NPS ARCHIVE
2000
LEWIS, D.

DUDLEY KNOX LIBRARY
NAVAL POSTGRADUATE SCHOOL
MONTEREY CA 93943-5101

USE OF INSULATING CONCRETE FORMS IN RESIDENTIAL HOUSING CONSTRUCTION

BY

DAN C. LEWIS

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING

UNIVERSITY OF FLORIDA
FALL 2000

IPS ARCHIVE
000
EWIS, D.

Thesis
L6513

DUDLEY KNOX LIBRARY
POSTGRADUATE SCHOOL
MONTEREY CA 93943-5101

LIST OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	iv
ABSTRACT	v
BIOGRAPHICAL SKETCH	vi
Chapter 1. Current Status of Insulating Concrete Forms	1
Introduction	1
Partnership for Advancement in Technology in Housing	3
National Construction Goals	3
Advanced Technologies for Foundations and Structural Walls	5
Evaluation Protocol for Insulating Concrete Forms	7
Structural Properties	8
Fire Properties	9
Thermal Properties	9
Termite Protection	10
Dampproofing and Waterproofing	10
Independent Laboratory	10
Construction Installation	10
Inspections	11
System Durability, Reparability, and Erection	11
Barriers to Advancement of ICF Technology	12
Barrier 1: Fragmented Industry Structure	12
Barrier 2: Exposure to Liability	12
Barrier 3: Cyclical Nature of Construction	13
Barrier 4: Lack of Access to Information	13
Barrier 5: Need for Education and Training	13
Barrier 6: Building Code and Product Approval Systems	13
Barrier 7: Limited Funding for Nonproprietary Research	14
Barrier 8: Market Resistance	15
Chapter 2. Types of Insulating Concrete Form Units	16
ICF Forms	16
Concrete Shapes	17
Parts of Typical ICF Systems	18
Manufacturing Process of Polysteel Blocks	19
Construction with Polysteel Blocks	21
Types of Plastic Foams	24
Structural Design of Insulating Concrete Forms	26

Chapter 3. Comparisons Between ICF and Wood Frame Homes 29
Description of Three Studies 29
VanderWerf Comparisons of ICF versus Wood Frame Homes 29
NAHB Study of Installed Cost, Acoustic, and Thermal Performance 30
NAHB Study of ICF Residential Construction—Demonstration Homes 31
Construction of ICF Home 32
Constructibility Design Issues 32
Construction Practices 33
ICF vs Wood Frame Homes 34
Construction Costs 34
Labor Cost 35
Material Cost 36
Total Cost 37
Construction Time 37
Effect of Price Fluctuations 38
Fire Resistance 40
Fire Resistance Requirements 40
Fire Performance 40
Acoustical Properties 42
Durability and Strength of Walls 43

Chapter 4. Energy Comparisons 46
Introduction 46
Thermal Mass 46
Consistency of Insulation 48
Air Infiltration 48
R-Values 49
Sources of Energy Loss 50
Energy Savings by Climate and Location 51
Cooling Savings 52
Heating Savings 53
Total Annual Savings 54
Life Cycle Costs 56

Chapter 5. Insulating Concrete Form Sources 58
Internet Sources 58
Magazines and Newsletters 59
Trade Organizations 59
ICF System Manufacturers and Installers 61

Chapter 6. Conclusions 62
Owner Perceptions 62
Key Observations 63
Future of ICF Construction 64

BIBLIOGRAPHY 66
APPENDIX: PowerPoint Presentation 68

LIST OF FIGURES

		Page
Figure 1-1	New ICF Home in Wisconsin	1
Figure 1-2	Low Income Housing in Las Cruces, New Mexico	1
Figure 1-3	Custom ICF Home in New Mexico	2
Figure 1-4	New 2-Story Home in Wisconsin	2
Figure 2-1	Three Types of ICF Forms	16
Figure 2-2	Examples of Flat Panel, Waffle-Grid, and Post-and-Beam Walls	17
Figure 2-3	Typical Components of ICF Blocks and Planks	18
Figure 2-4	Manufacturing Process of ICF Blocks	19
Figure 2-5	Typical Details for Common Construction Applications	21
Figure 2-6	Basic Building Procedures for ICF Block Installation	22
Figure 2-7	Sample Design Table for Construction with Polysteel Block	23
Figure 2-8	Types of Plastic Foams Used in ICFs	24
Figure 2-9	Forces Analyzed During ICF Wall Construction	26
Figure 2-10	Transition Stages on Interaction Diagram	27
Figure 3-1	Distribution of Homes for VanderWerf Energy Study between ICF and Wood Frame Houses	30
Figure 3-2	Floor Plan for Three Homes in Chestertown, Maryland Used for NAHB Research Center Study	31
Figure 3-3	ICF vs. Wood Frame: Labor Cost versus Wall SF	35
Figure 3-4	ICF vs. Wood Frame: Labor Cost versus Floor SF	35
Figure 3-5	ICF vs. Wood Frame: Material Cost versus Wall SF	36
Figure 3-6	ICF vs. Wood Frame: Material Cost versus Floor SF	36
Figure 3-7	ICF vs. Wood Frame: Total Cost versus Wall SF	37
Figure 3-8	ICF vs. Wood Frame: Total Cost versus Floor SF	37
Figure 3-9	ICF vs. Wood Frame: Total Wall Cost/SF for 25% ICF Cost Decrease and 25% Wood Frame Increase	38
Figure 3-10	ICF vs. Wood Frame: Total Floor Cost/SF for 25% ICF Cost Decrease and 25% Wood Frame Increase	38
Figure 3-11	Example of Net Cost Savings due to ICF Construction	39
Figure 3-12	Fire Rating Performance of ICF vs. Wood Frame Walls	41

Figure 3-13	Flame Spread Performance of ICF vs. Wood	41
Figure 3-14	Sound Attenuation of Wood Frame Wall vs. ICF	42
Figure 3-15	Sound Reduction Comparison between ICF and Wood Frame House	43
Figure 3-16	Relative Damage by Type of Wall Material and Debris Speed	44
Figure 4-1	Thermal Mass Comparison between ICF and Wood Frame Walls	47
Figure 4-1	Consistency of Insulation Coverage between ICF and Wood Frame Walls	48
Figure 4-3	Air Infiltration Comparison between ICF and Wood Frame Walls	49
Figure 4-4	Sources of Energy Loss in Typical House	50
Figure 4-5	ICF Contribution to Energy Loss Reduction	50
Figure 4-6	Heating and Cooling Degree Days for Cold, Moderate, and Warm Climates	51
Figure 4-7	Annual Cooling Savings in Cold, Moderate, and Warm Climates	52
Figure 4-8	Annual Savings per Square Foot for Hot, Moderate, and Cold Climates	52
Figure 4-9	Annual Heating Savings in Cold, Moderate, and Warm Climates by House Size	53
Figure 4-10	Heating Savings per SF of House Size in Cold, Moderate, and Warm Climates	53
Figure 4-11	Total Annual Energy Savings by House Size in Cold, Moderate, and Warm Climates	54
Figure 4-12	Total Annual Savings per SF of House Size in Cold, Moderate, and Warm Climates	54
Figure 4-13	Annual Total Energy Savings Per Total Cooling and Heating Degree-Days in Cold, Moderate, and Warm Climates	55
Figure 4-14	Number of Years to Recover Energy Savings Based on 3% Rate of Return on Annual Savings	57

LIST OF TABLES

Table 2-1	Properties of Foam Used in Insulated Concrete Forms	25
Table 2-2	Typical Load and Concrete/Steel Specifications	28
Table 6-1	List of ICF Manufacturers	61

ABSTRACT

The use of Insulated Concrete Forms (ICFs) represents a viable alternative construction method to conventional wood framing in today's residential housing marketplace. The Partnership for Advancing Housing Technology, a joint Government-private venture, will further propel the advancement of ICF construction. The National Evaluation Service is currently standardizing the ICF industry building requirements for inclusion in model building codes. There are three types of ICF building units and four types of foam, each with different properties and structural design requirements. Many of ICF material properties provide advantages over wood frame construction, notably in better insulation R-values, fire resistance, sound reduction, air infiltration, consistency of insulation, and strength and durability against severe storms. The cost to build ICF foundations and exterior walls is double the cost of wood frame construction, but overall ICF housing prices are 2-4% more than similar wood frame houses. Homes constructed from ICFs use less energy and therefore will save the owner in energy costs. An analysis of energy savings in cold, moderate, and warm climates and a basic economic analysis can be performed to determine the relationships between the location, energy cost savings, and the added purchase expense. A fairly new industry, the Internet provides a lot of data for ICFs and related construction technologies.

30 Nov 00

From: LT Dan C. Lewis, CEC, USN 519-94-0947
To: Code 031A

Subj: FORWARDING OF MASTERS REPORT

Ref: (a) NAVPGSCOL Instruction 1520.1E
Encl: (1) Masters Report (2 Copies)

1. Enclosure (1) is forwarded, per reference (a).

2. If you have any questions or need additional information regarding the subject report, please email me at lewisdcl@yahoo.com.

RECEIVED
DEC 1 3 2000
BY:

BIOGRAPHICAL SKETCH

Dan C. Lewis, a U.S. Navy Lieutenant in the Naval Civil Engineer Corps (CEC), joined the CEC Collegiate Program in 1989, graduating from the University of Idaho with a Bachelor of Science in Civil Engineering in December 1991. Dan C. Lewis earned a Master of Engineering Degree in December 2000 from University of Florida.

After graduating in 1991, Dan C. Lewis worked for the Idaho Department of Transportation in Lewiston, Idaho, before entering Officer Candidate School at Newport, Rhode Island, where he was commissioned as an officer in July 1992. While in the Navy, Lieutenant Lewis has served as Assistant Resident Officer in Charge of Construction at Naval Air Station Memphis in Millington, Tennessee; Facilities Engineering Department Head, PWC Liaison at Joint Task Force-Operation Pacific Haven, and Supervisory Contracting Officer at Public Works Center, Guam; and Delta Company Commander, Officer-in-Charge of Details at Guantanamo Bay, Cuba, and Soto Cano, Honduras, and Assistant Operations Officer at Naval Mobile Construction Battalion SEVEN, homeported in Gulfport, Mississippi.

Dan C. Lewis is qualified as a Navy Seabee Combat Warfare Officer and should be registered as a Professional Engineer in the state of Idaho by February 2001. He is also a member of Society of American Military Engineers, American Society of Civil Engineers, Tau Beta Pi engineering honor society, Chi Epsilon civil engineering honor society, Phi Kappa Phi honor society, and Delta Tau Delta fraternity.

Dan C. Lewis is married to the former Leigh Ann Fargo of Nezperce, Idaho. They have two sons, Aaron and William.

Chapter 1. Current Status of Insulating Concrete Forms

Introduction

Insulated Concrete Forms (ICFs) represents an innovative construction technique that provides an alterative to conventional timber formwork commonly used in the construction industry. Not a new technology, ICFs have been utilized for over 20 years and have been gaining ground in concrete construction applications.

Figure 1-1. New ICF Home in Wisconsin [icfweb.com, 2000]

ICFs are hollow foam blocks or panels that are stacked to form the shape of an exterior wall of a building. Reinforcement and concrete are then placed inside of the foam form, thereby creating a foam-concrete-foam sandwich. The forms are left in place. The exterior finish, stucco, siding, etc., can be attached to the walls. The interior wall finish can also be attached to the wall. Figures 1-1 through 1-4 include several examples

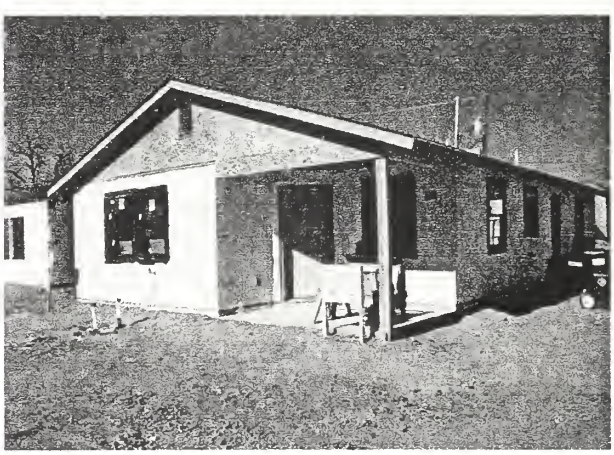


Figure 1-2. Low Income Housing in Las Cruces, New Mexico [icfweb.com, 2000]

ICF structures [www.icfweb.com, 2000]. ICFs are used in a variety of construction applications, ranging from single unit residential homes to condominiums to industrial buildings. This paper will examine the following aspects of using ICFs in residential construction:

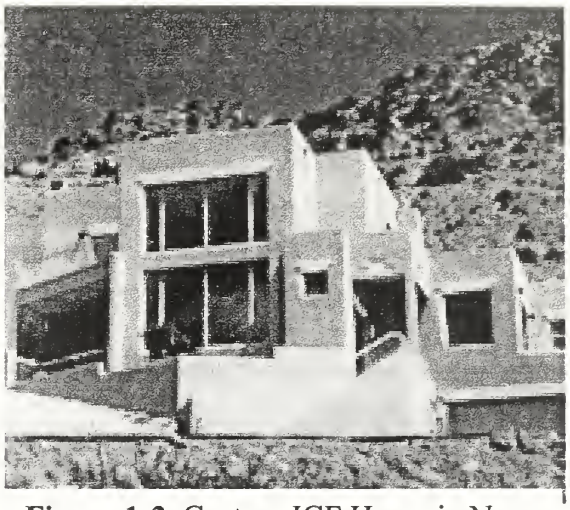


Figure 1-3. Custom ICF Home in New Mexico [icfweb.com, 2000]

- The Partnership for Advancing Technology in Housing
- The Evaluation Protocol for Insulating Concrete Forms
- The types of ICF form units and polystyrene manufacturing process
- Comparisons between ICF and wood frame construction, including cost, durability, acoustic, fire resistance, and other properties
- Energy savings potential between ICF and wood frame construction for cold, moderate, and warm climates
- Design parameters for the use of ICFs
- ICF Sources

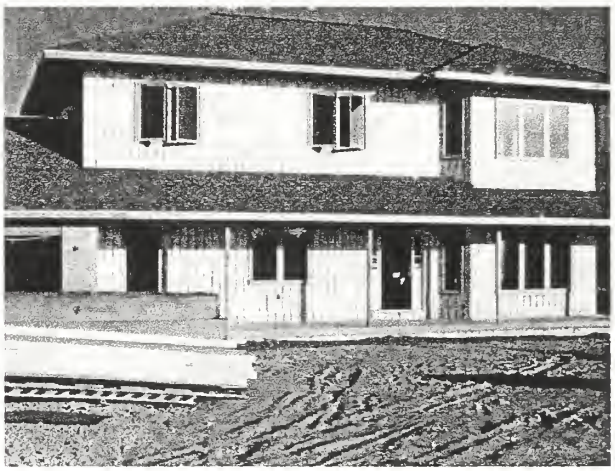


Figure 1-4. New 2-Story ICF Home in Wisconsin [icfweb.com, 2000]

Partnership for Advancing Technology in Housing

One of the major proponents for the future advancement of ICF construction includes the Partnership for Advancing Technology in Housing (PATH), a voluntary initiative between the Federal Government and private industry inaugurated by President Clinton in 1998 to accelerate the creation of widespread use of advanced technologies to "radically" improve the quality, durability, environmental performance, energy proficiency, and affordability of our nation's housing. This program is a three-year process to establish National Construction Goals for the residential housing industry. [PATH, 2000]

National Construction Goals

In January 1998, the NAHB Research Center published a report for the U.S. Department of Housing and Urban Development titled "Building Better Homes at Lower Costs: The Industry Implementation Plan for the Residential National Construction Goals". The original National Construction Goals included the following, with the first two goals being the main focus for immediate action:

1. 50 percent greater durability and flexibility. The use of ICFs are much more durable than wood framed construction.

2. 50 percent reduction in project delivery times. ICF production rate is comparable to wood frame construction overall, and has the potential to speed up as builders become more familiar with ICF installation.

3. 50 percent reduction in operations, maintenance, and energy costs. ICF construction is an extremely viable alternative toward meeting this goal, as discussed during this paper.

4. 30 percent increase in occupant productivity and comfort. ICF systems are an extremely viable alternative toward meeting this goal, as will be discussed with owner perceptions later in this paper.

5. 50 percent fewer facility-related illnesses and injuries.

6. 50 percent less waste and pollution. ICFs greatly reduce waste, as the forms are left in place during construction.

7. 50 percent reduction in construction illnesses and injuries. The use of ICFs, which are very light Styrofoam forms, will reduce construction-related injuries compared to wood frame construction. The impact of carting around heavy lumber all day versus light forms can be very beneficial toward meeting this goal.

One of the main points of the goals is that the barriers to advancement need to be reduced so that new technologies can be accepted. The main social and technical barriers to new technologies are presented later in this chapter.

Advanced Technologies for Foundations and Structural Walls

The NAHB, through the PATH program, is examining many advancing technologies to meet the HUD National Housing Construction Goals. The use of ICFs is not the only technology being developed through the PATH program. The two main uses of ICFs include foundations and exterior walls. Some of the other technologies being researched for advancement under the PATH program include the following:

Foundations:

- Autoclaved Aerated Concrete
- Crystalline Concrete Waterproofing
- Fly Ash Concrete and Fly Ash Based Cement
- Foundation Drainage Panels
- Frost Protected Shallow Foundations
- Pumice-Crete
- Wood/Concrete Masonry Units
- Wood Foundations
- Precast Concrete Foundation Panels
- Manufactured Housing Disaster-Resistant Pier Systems

Exterior Walls:

- Cellular PVC Lumber
- Composite Panel Housing System
- Engineered Wood Wall Framing
- Fastenerless Steel Framing-Clinching
- Fiber Cement Siding
- Foam Cap Thermal Breaks for Steel Studs
- Foam Plastic Exterior Millwork
- Insulative Vinyl Siding
- Modular Shear Wall
- Mortarless Brick Siding
- Plasic Composite Nails
- Spray Foam Insulation
- Straw Bale Construction
- Structural Insulated Panels
- Vacuum Insulated Panels

The National Construction Goals were refined into seven main strategies; six of the seven strategies were can be applied to ICFs and are listed below:

1. Establish and maintain an information infrastructure responsive to the needs of builders, designers, subcontractors, manufacturers, code officials, and consumers. Communication up and down the logistics supply is discussed as a barrier to advancement later in this chapter.

2. Develop and implement improved methods for assessing and increasing the durability of specific types of building products. The Evaluation Protocol for ICFs, which is presented later this chapter, discuss the methods used to test durability and strength.

3. Improve the efficiency of the housing production process.

4. Improve the efficiency of the regulatory and new product approval processes. The Evaluation Protocol for ICFs was written so that ICF technology and building practices could be integrated into the model building codes.

6. Foster the development and commercialization of innovative products and systems based on input from the building community. This is an area that ICFs can gain valuable press and advertisement for increased use.

7. Expand markets and marketability for products and systems that reduce costs or improve durability. ICFs, while having a higher capital

cost, as will be discussed in Chapter 3, have lower life cycle costs due to the energy savings. For ICFs to expand, the capital costs will have to be competitive with conventional wood frame construction to entice the money-strapped homebuyer.

Evaluation Protocol for Insulating Concrete Form Technology

As a fairly new advanced building technology, ICFs do not have a much documentation regarding design performance and standard building practices, and consequently, have not been included into model building codes. As such, gaining construction approval for ICF construction projects can require full sets of engineered designs, which can be much more work than required for typical wood-framed construction. [PBR, January 1, 1998]. To facilitate the integration of new technologies into model building codes, the National Evaluation Service (NES) evaluates building technologies for compliance with model building codes that are adopted at the Federal, State, and local government levels. NES, in support of the Partnership for Advancing Technology in Housing (PATH) program sponsored by the U.S. Department of Housing and Urban Development (HUD), has published "The Evaluation Protocol for Insulating Concrete Form Technology" to standardize ICF building technology concepts and building details for universal and general acceptance by the building industry. This draft protocol process has been process for over 2 years and a final draft was released for public comment on November 01, 2000

for two months. The goals of the evaluation protocol are to provide the following: [NES, 2000]

- Uniformity in data acquisition and analysis
- Enhanced cost effectiveness of an evaluation
- Uniform comparison of various ICF technologies
- An understanding of what is expected of the technology
- More timely technology evaluation and deployment

Specifically, the Evaluation Protocol will establish requirements for:

- Structural Properties
- Fire Properties
- Thermal Resistance Properties
- Durability
- Constructibility
- Maintenance

The Evaluation Protocol defines and identifies ICF Wall Systems, including definitions of physical components for flat ICF wall systems and waffle grid form walls systems. Minimum dimensional requirements for the ICF wall and blocks are specified for construction use. Figures of standard ICF wall components and dimensions are provided in Chapter 3. The following sections provide more details regarding the evaluation requirements:

Structural Properties. Engineering structural design for ICF flat, waffle-grid, and screen-grid systems will comply with the main ICF design documents, the Portland Cement Association's *Prescriptive Method for Insulating Concrete Forms in Residential Construction* or *Structural Design of Insulating Concrete Forms Walls in Residential Construction,* or the *American Concrete Institute (ACI) 318.* [NAHB, May 1998]

Qualification testing for ICF materials shall address material properties, stresses, deformations, ductility, and limit states. The structural qualification tests, each conforming to a specific ASTM standard, can include a Wall Compression Test, Wall Flexural Test, Wall Flexural-Compression Test, Wall Shear Test, Anchor Bolt Test, Concrete Test, and Reinforcing Steel Yield Strength Test. Design capacities will be based on the Working Stress Procedure or the Strength Design Procedure, with specific Safety Factors specified for anchorages, bearings, bending, compression, shear, and tension. Concrete and reinforcement shall comply with ACI 318 or PCA EB118.

Fire Properties. For combustible construction, Insulating Concrete Forms must conform to ASTM E 84 for Flame Spread and Smoke Developed properties. For non-combustible construction, ICFs must meet ASTM E 84 requirements for Flame Spread and Smoke Developed, and National Fire Protection Agency (NFPA) 268 for Potential Heat, NFPA 268 for Ignition Resistance, and ASTM E 108, Two Story Fire Test, or NFPA 285 for Flame Propagation. Additionally, foam plastic insulation on interior walls must be separated by regular gypsum wallboard or equivalent barrier to comply with ASTM E 119 for a 15-minute fire rating.

Thermal Properties. Testing for Thermal Resistance is governed by ASTM C 236. Design testing shall be based on mean temperature of 75 degrees F+ 5 degrees F, and conditioning tests shall be based on tests at 140 degrees F dry heat and 5 degrees F for 90 days. The determination of

Thermal Resistance shall be determined by the *ASHRAE Handbook Fundamentals*.

Termite Protection. The probability of termite infestation is determined by location. For "very heavy" areas in the southern states, certain types of expanded polystyrene ICFs shall not be installed on the exterior face or under the interior or exterior foundation walls or slab foundations below grade. The clearance between foam installed above grade and exposed earth shall be at least six inches.

Dampproofing and Waterproofing. Exterior foundation walls that retain earth and enclose habitable space shall be dampproofed from the top of the footing to the finished grade, and if in area with a high water table, the walls shall be waterproofed with a membrane.

Independent Laboratory. For ICF materials, several requirements for independent laboratory qualifications and test reports are specified. For example, the independent laboratory is required to be listed by the National Evaluation Service. For example, the Keeva ICF Post-and-Beam system uses the Underwriters Laboratory for quality control certification [Keeva, 1997].

Construction Installation. Documentation of the construction of ICFs have several requirements, including placement on foundation, form installation, concrete mix design, reinforcing steel and placement, bracing, placement of concrete, consolidation of concrete, connection details, material compatibility for exterior finishes, interior finishes, waterproofing and

dampproofing, and utility installations (electrical, plumbing, HVAC, telephone, etc.)

Inspections. Minimum levels of inspection are specified based on the classification whether the construction is defined as a Nonessential or Essential Facility, according to ASCE 7 Table 1-1. For Nonessential Facilities, which include One and Two Family Dwellings, inspection is required by the appropriate local authority after the ICF forms are installed and braced, reinforcing steel placed, and plumbing, mechanical, and electrical rough inspections are approved. Inspection requirements for Essential Facilities are basically the same as Nonessential Facilities.

System Durability, Reparability, and Erection. The durability of ICF Wall systems in a harsh environment is insured by several features that are included in the design and manufacturers details, which require waterproofing or dampproofing below grade, exterior veneers for protection from weather, interior veneers for protection from normal use and fire, and termite protection for applicable areas. For repairs to the interior and exterior veneers and for structural repairs to the ICF Wall system, methods are specified for the replacement of damaged veneers, damaged insulating foam, and chipped concrete. Manufacturers of ICF Wall systems provide installation/erection procedures, which equipment needs, working space requirements, and guidelines for field repairs.

Barriers to Advancement of ICF Technology

Although Insulating Concrete Forms have a lot of advantages, the advancement of ICF technology faces many societal and industry barriers. In order to develop strategies to further advancement in the innovation of the residential construction industry, a panel of experts in the construction industry developed list of barriers described below in order to create strategies for overcoming the barriers. [NAHB, January 1998]

Barrier 1: Fragmented Industry Structure. The housing construction industry includes a complex and fragmented chain of production and supply. The production chain extends from raw material suppliers and product manufacturers through distributors and wholesaler to commercial and private housing construction contractors. In order change the supply chain for new technologies, good communication from the contractors to the distributors to the manufacturers is vital for the ICF industry to grow.

Barrier 2: Exposure to Liability. Once manufacturers develop a reliable product, which means that the products do not have high callback risk and potential litigation risk, they are reluctant to develop new products and discourage new builders from requesting new products. An early drawback of a new product is that the manufacturer may excessively raise prices to cover the probability of callbacks while the product is still being perfected, and potential defects can raise safety, and consequently, litigations concerns.

Barrier 3: Cyclical Nature of Construction. The history of housing construction has shown a remarkable cyclic pattern, with the rise and fall of interest rates as one of the key proponents. New technologies take a long time to research and introduce into the mainstream housing construction industry. Short-term fluctuations in the interest rate affect introduce more risk for new technologies more than established construction methods and materials.

Barrier 4: Lack of Access to Information. Because manufacturers and distributors are reluctant to introduce new products, contractors do not openly have access to new technologies with their main distributor contacts. The contractors ultimately are more comfortable with the methods they have always used, and are more likely to resist new technologies.

Barrier 5: Need for Education and Training. Even if contractors are interested in a new product or technology, the contractor is unlikely to assume the risk of using new product without proper education and training, which could be a significant capital investment of time and money for the contractor. The entire team of parties involved in the homebuilding process need to be included in education and training of new technologies; these parties include architects, designers, home builders, workers, trade contractors, installers, plan reviewers, and inspectors.

Barrier 6: Building Code and Product Approval Systems. Product developers face the difficult obstacle of creating a new product that meets

building codes. Gaining acceptance into a building code is difficult, as building codes are approved at several levels, with ultimate approval at a local level. There are three main organizations that publish housing codes, including the Building Officials and Code Administrators International (BOCA International), International Conference of Building Officials (ICBO), and the Southern Building Code Congress International (SBCCCI). The three groups basically represent different parts of the country; BOCA covers the Midwest and Northeast, ICBO in the West, and SBCCIA in the South. A fourth group, the Council of American Building Officials (CABO), was created to serve as a federated organization of the other three groups. [PBR, Feb 97] The three regional groups of BOCA, ICBO, and SBCCCI, along with CABO, have joined into the development of a new organization, the International Code Council, which is currently working on the International Building Code and the International Residential Code. Given all these groups and their changing dynamics, gaining universal building code acceptance for new products will continue to be a challenge [PBR, January 1, 1998].

Barrier 7: Limited Funding for Nonproprietary Research. Most of the new products introduced are funded privately, with a sole company owning the technology. This kind of research does not encourage the housing industry to accept new technologies. An analogy would be Apple Computer and their reluctance to share their proprietary knowledge for the eventual development of Apple clones and the widespread market dominance that

would result from its use and product competition; consequently, their market share became very small and insignificant with the development of "IBM-compatible" computers.

Barrier 8: Market Resistance. Homebuyers are also reluctant to new technologies, particularly if the new product visibly differs from conventional products. Homebuyers' reluctance can be overcome with targeted marketing campaigns that clearly address the advantages and benefits. Additionally, model homes showcasing the new technology must be available for the public to view.

Chapter 2. Types of Insulating Concrete Form Units

ICF systems have two major attributes that describe the specific kind of building unit and the respective design properties and assumptions. The first attribute is the kind of ICF form used in construction, and the second is the shape of the concrete within the form.

ICF Forms

Three different kinds of ICF forms used in construction practice: Panels, Planks, and Blocks. These three types of ICF forms, shown in Figure 2-1, all use the same concept of using two foam pieces fastened together with

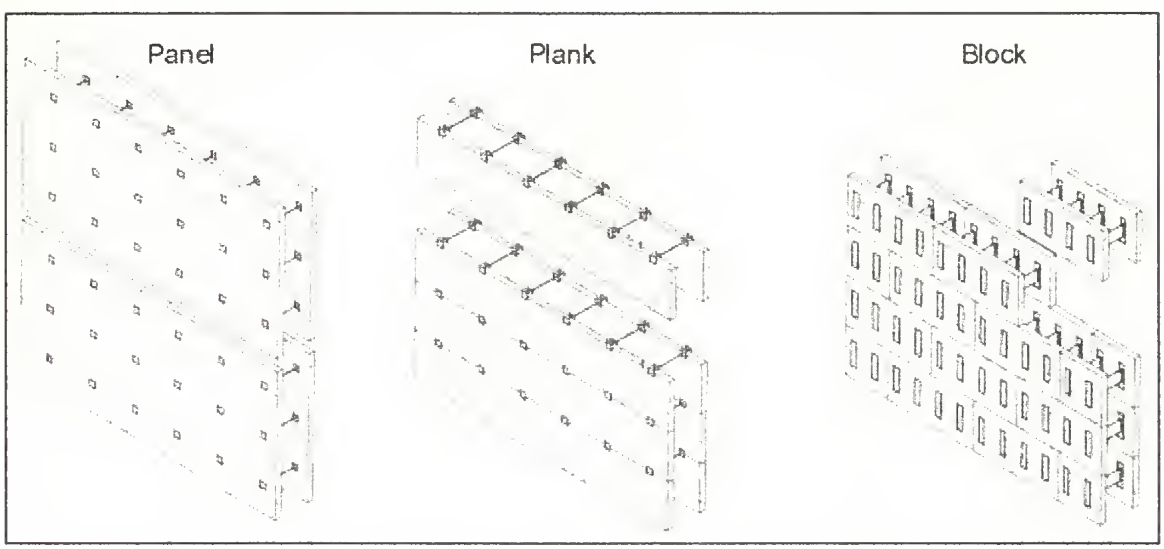


Figure 2-1. Three Types of ICF Forms [VanderWerf et al., 1997]

reinforced concrete placed inside.

The panel is the largest units, measured typically in 4 foot by 8-foot sections. Planks are typically 1 foot by 8 feet. The planks are fastened together with plastic ties. Blocks are the smallest unit, and are typically in

16 inch by 4-foot sections, and are connected with special grooves along the edges known as interconnects. [VanderWerf et al., 1997]

Concrete Shapes

The shapes of concrete within the forms include Flat, Grid, and Post-and-Beam. The Flat systems form a solid concrete slab and resemble the wall that would be placed using conventional formwork. Grid systems have a wavy center, where the concrete varies in thickness from thin to thick, with the shape resembling a breakfast waffle. A Post-and-Beam system is

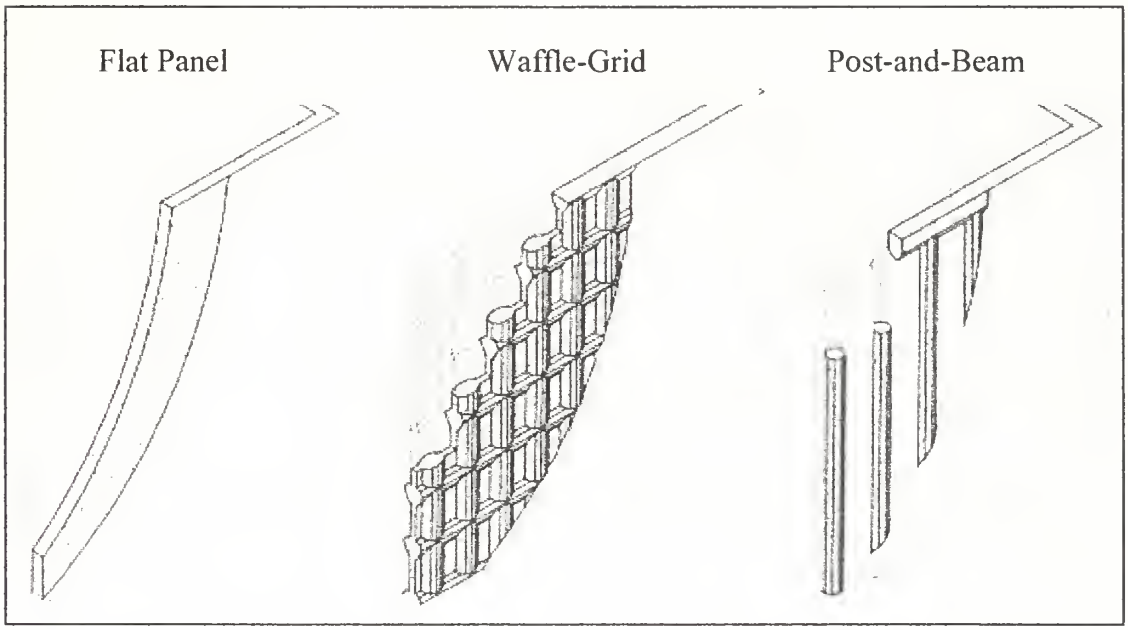


Figure 2-2. Examples of Flat Panel, Waffle-Grid, and Post-and-Beam ICF Walls [VanderWerf et al., 1997]

constructed with concrete members being poured at specified or varied distances, creating concrete posts. Figure 2-2 shows a cutaway view of these three systems:

Parts of Typical ICF Systems

Each manufacturer has their own parts, many patented, to provide for the interconnecting, ties, corners, bracing, and fastening surfaces for exterior and interior mounting of utilities and wall coverings, etc. Figure 2-3 depicts the common parts of two typical ICF systems:

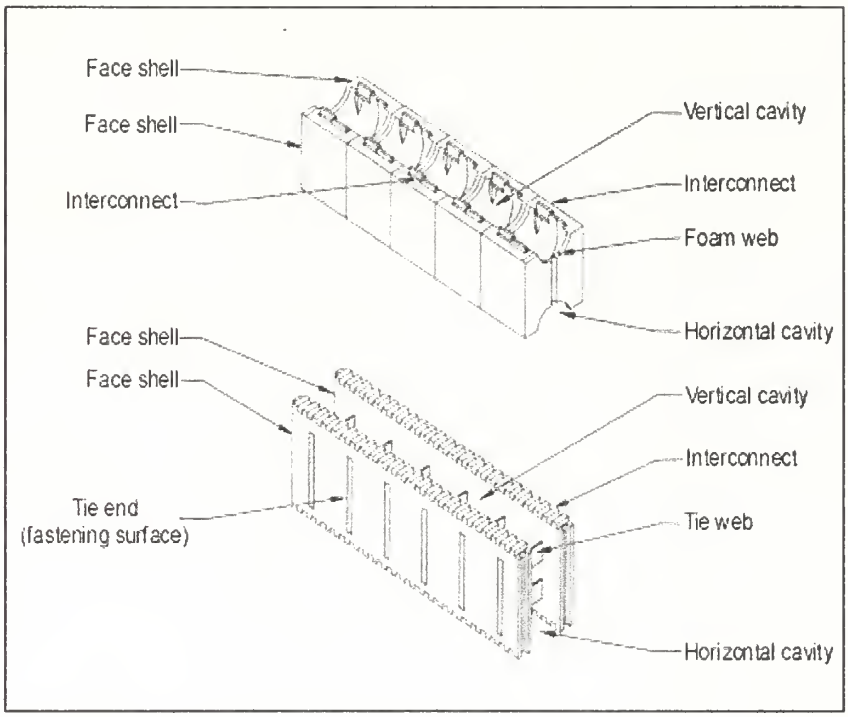


Figure 2-3. Typical Components of ICF Blocks and Planks [VanderWerf et al., 1997]

Some of the main differences between the various building units are within the Tie Webs and the Tie End. The Tie Webs are typically either rigid plastic or galvanized steel. The sample obtained from American Polysteel is a grid block that uses a galvanized grid for the Tie Web. The Tie Ends for the fastening surface are pieces of galvanized sheet metal folded. Figure 2-4, a American Polysteel block, shows the Tie Web, Tie End, Horizontal and Vertical Cavities, Foam Web, Interconnects, and Face Shell.

Manufacturing Process of Polysteel Block

Before the ICF building materials are installed on a jobsite, they go through a careful and deliberate manufacturing process. Figure 2-4, the manufacturing process for American Polysteel blocks in Gainesville, Florida,

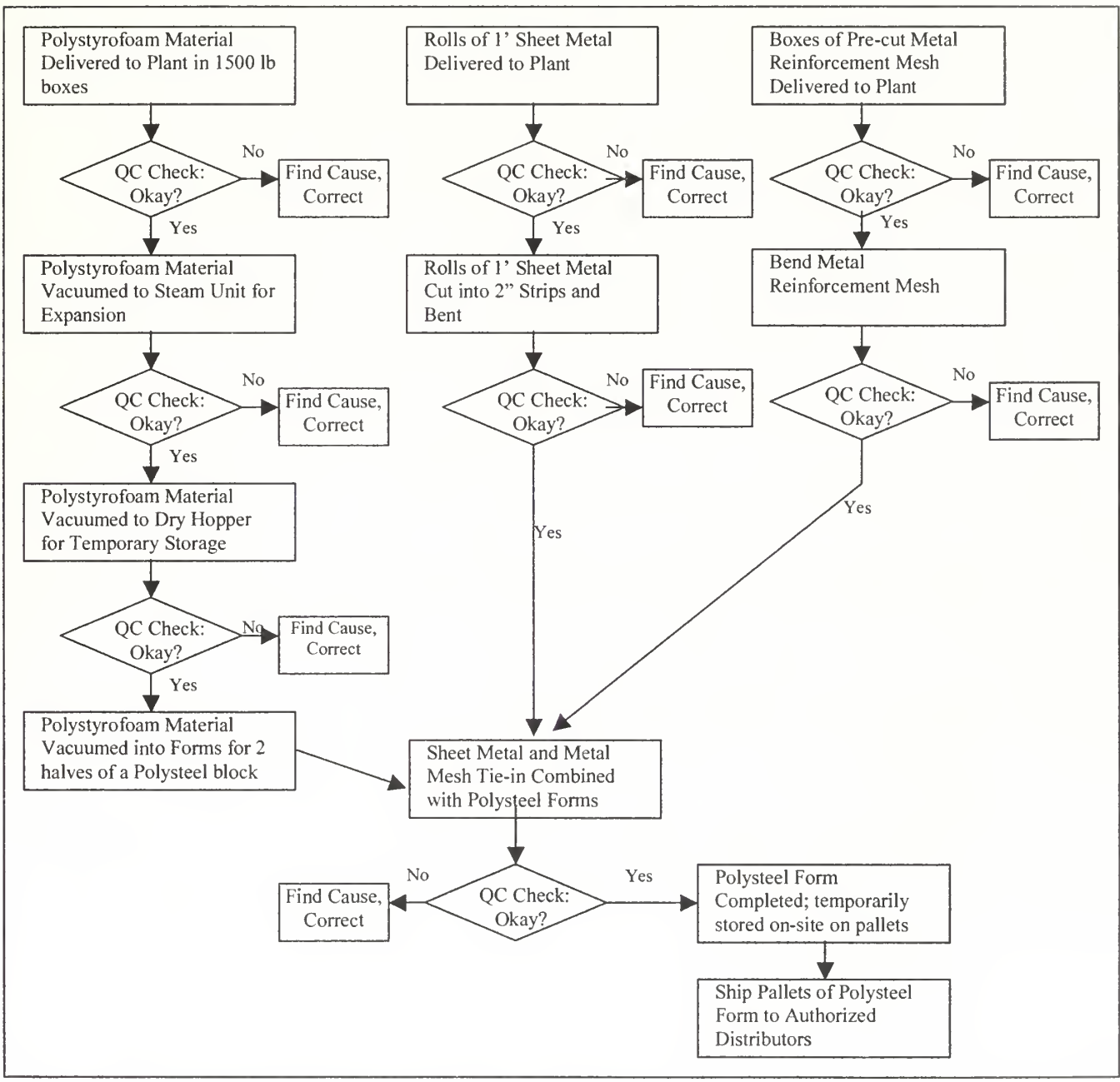


Figure 2-4. Typical Manufacturing Process of ICF Blocks

represents the typical manufacturing process of the foam blocks. The American Polysteel plant produces over 1000 blocks a day in a combination of 6" and 8" block. The plant itself was kept very clean and had a very professional appearance. As shown in the process, only an authorized distributor and contractors are allowed to sell or use Polysteel building system. Because the work is so repetitive, the skill required to operate the machinery or build the block is very low, and consequently, the labor wages are in the minimum wage range. [American Polysteel, May 2000]

The plant has two machines for producing forms, of which only one was operating during my site visit. The large machines themselves are not a regular preventative maintenance schedule, and therefore, planned down time for maintenance is not scheduled.

There are several quality control checks throughout the process to ensure that a high-quality product is manufactured. The key quality control checks include those involving the material that makes up the foam polystyrene, as it is delivered in a form resembling laundry detergent, then expanded by steam into little Styrofoam balls, and eventually molded into Polysteel Form blocks. The temperature, humidity, condition of machine, quality of materials all play into the quality control equation.

Construction with Polysteel Blocks

American Polysteel Systems, as well as other ICF systems manufacturers, have standard details for installation of the blocks and for connections including basements, windows, roof trusses, utilities, exterior and interior finishes, etc. Figure 2-5 shows some of the standard connections for a typical exterior wall and a basement that Polysteel recommends for use with their blocks. Also included in Figure 2-5 is a picture showing the

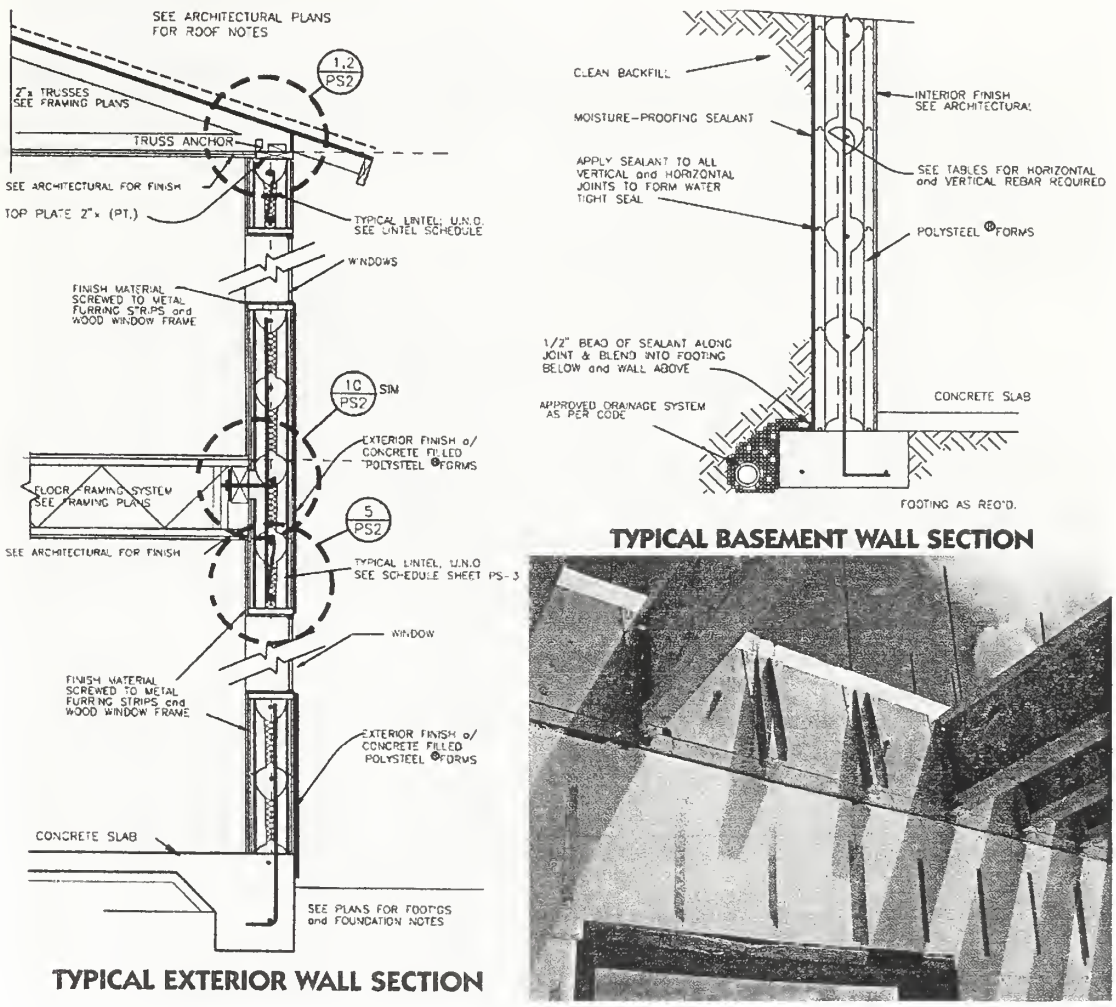


Figure 2-5. Typical Details for Common Construction Applications [American Polysteel, 1999]

installation of floor joists above a basement. [American Polysteel, 1999] Many ICF construction companies have engineers who can adapt a wood frame design to an ICF design; this entails increasing the walls thickness without losing interior floor space [Amhome, 2000].

Polysteel engineers, as other ICF systems manufacturers, have calculated the required amount of concrete and steel reinforcement for various types of housing and building applications. Most ICF manufacturers have basic rules-of-thumb for estimating the volume of concrete for their

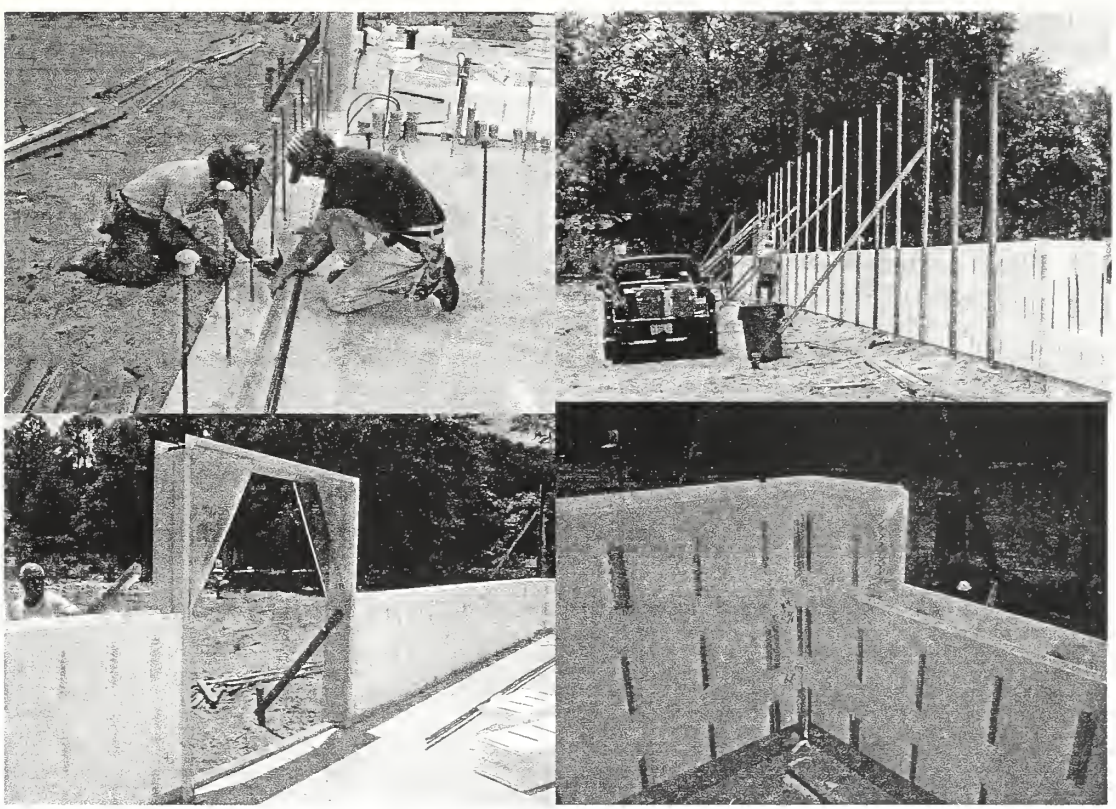


Figure 2-6. Basic Building Procedures for ICF Block Installation. [R.O. Camp, 2000] Top Left: Setting toe-board for ICF block base course setting
Top Right: Setting support for ICF block wall for concrete placement
Lower Left: Setting door buck during ICF block layout
Lower Right: Construction of corner with ICF blocks

products. For example, Eco-Block specifies 0.10 cubic yards of concrete per block for a 6-inch wall, which is also stated as taking the number of blocks

SAMPLE DESIGN TABLE
REINFORCEMENT REQUIREMENTS FOR POLYSTEEL BUILDINGS

FOR 1-STORY (OR TOP OF 2-STORY)				
	6 inch Forms		8 inch Forms	
Spans Between Bearing Walls	Seismic Zones 0, 1, 2A, 2B	Seismic Zones 3, 4	Seismic Zones 0, 1, 2A, 2B	Seismic Zones 3, 4
0 to 60 feet	V = #4 @ 24" O.C. H = #4 @ 48" O.C.	V = #3 @ 12" O.C. H = #3 @ 16" O.C.	V = #4 @ 24" O.C. H = #4 @ 48" O.C.	V = #3 @ 12" O.C. H = #3 @ 16" O.C.
FOR BOTTOM STORY OF 2-STORY (NOT FOR BASEMENTS)				
	6 inch Forms		8 inch Forms	
Spans Between Bearing Walls	Seismic Zones 0, 1, 2A, 2B	Seismic Zones 3, 4	Seismic Zones 0, 1, 2A, 2B	Seismic Zones 3, 4
0 to 40 feet	V = #4 @ 24" O.C. H = #4 @ 48" O.C.	V = #3 @ 12" O.C. H = #3 @ 16" O.C.	V = #4 @ 24" O.C. H = #4 @ 48" O.C.	V = #3 @ 12" O.C. H = #3 @ 16" O.C.
40 to 48 feet	V = #5 @ 24" O.C. H = #4 @ 48" O.C.			
48 to 60 feet	V = #4 @ 12" O.C. H = #4 @ 48" O.C.			

NOTES:
1. V = Vertical Reinforcement, H = Horizontal Reinforcement.
2. Table 1 requires a minimum of 3,000 psi concrete and 40,000 psi deformed steel rebar.
3. Table 1 assumes a wind speed of 100 mph (design wind load of 34.7 lbs/ft^2).
4. Table 1 assumes unsupported wall heights that do not exceed 10 feet from floor to ceiling.
5. Table 1 assumes a roof live load (snow load) of 30 lbs/ft^2 and a floor live load of 40 lbs/ft^2.
6. Table 1 assumes roof and floor dead loads of 15 lbs/ft^2.
7. Table 1 should not be used for basements. (See Tables 2 through 5 for basement rebar requirements).

Figure 2-7. Sample Design Table for Construction with Polysteel Block [American Polysteel, 1999]

and dividing by 10 [Eco-Block, May 2000]. Figure 2-6 shows some of the basic steps in setting up the ICF blocks before placing concrete. In addition to a sample design table for reinforcement requirements for Polysteel buildings, shown in Figure 2-7, Polysteel also provides engineered tables for reinforcement in building footers, deep and shallow lintels, basement walls (based on soil pressure), openings (windows, doors, etc.), and one and two story buildings to use in conjunction with their building system. The

Evaluation Protocol discussed in Chapter 1 will help to standardize some minimum requirements for all ICF construction.

Some of the basic tools for constructing ICF walls include a table or miter saw, regular hammer, level strings, movable scaffold system, standard framing lumber to build door and window bucks if premanufactured bucks are not provided with the ICF system, mortar mix for first row of block, and a concrete pump with a reduction piece not over 2.5 inches [K-X Faswall, 2000]

Types of Plastic Foams

This section discusses the types of plastic foams used in ICF construction and their basic properties. Figure 2-8 shows the breakdown of foam types by relationship. Most ICF systems use a form of polystyrene

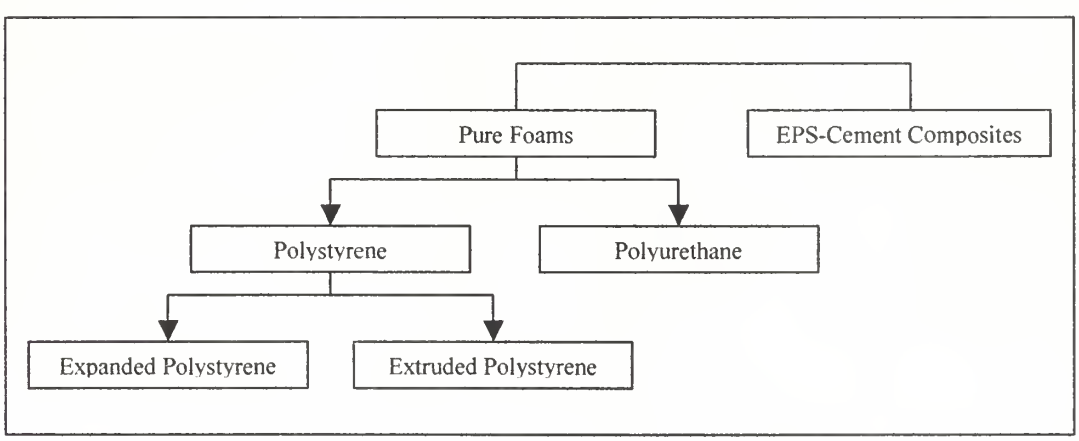


Figure 2-8. Types of Plastic Foams Used in ICFs [VanderWerf et al., 1997]

foam, which is either expanded polystyrene (EPS) or extruded polystyrene (XPS). EPS, which would include the American Polysteel block, is made by expanding small foam beads into a closed-cell, cellular form. XPS, a continuous extrusion process, ultimately creates a homogenous cellular

structure. For polyurethane, the foam is produced using a chemical and heat reaction with a form of isocyanate and polyol. The blowing agent froths the mixture with tiny cells to produce the foam. EPS-cement composites combine EPS heads and Portland cement; the EPS heads are not heated to fuse together as other EPS foams, but are cemented to form a very lightweight insulating concrete.

Table 2-1 shows some of the typical properties measured in the plastic forms used in ICFs. Note the main properties include the density, R value per inch of thickness, strength (compressive, flexural, tensile, and shear), water absorption, flame spread, smoke developed, and cost. The EPS provides the best performance only for tensile strength and smoke enveloped,

Property	EPS	XPS	Composite	Polyurethane
Density (pcf)	1.35-1.8	1.6-1.8	21.0	2.0
R per inch (m^2 * °C/W)	4.17-4.35	5.0	3.0	5.9
Compressive Strength (psi)	15-33	24-40	72	30
Flexural Strength (psi)	40-75	50-60	75	
Tensile Strength (psi)	88-127	45-75	42	
Shear Strength (psi)	26-37	30-35		35
Water vapor permeance/inch	1.0-3.5	1.1		2.0
Water absorption (%)	<3.0	<0.3		2.0
Flame Spread	10	5		20
Smoke Developed	125	165		250
Cost ($/bd ft)	$0.17	$0.35		$0.70

Table 2-1. Properties of Foams Used in ICFs [VanderWerf et al, 1997]

but is the most inexpensive material. The XPS provides the best performance for water absorption and flame spread, and was the second most inexpensive. The composite cement-foam was the densest material, with the highest compressive and flexural strength. Polyurethane foam provides the highest R-value per inch and water vapor permeance, but had the highest

flame spread and smoke enveloped of the types of foam and was the most expensive.

Structural Design of Insulating Concrete Forms

The construction of ICF walls are structurally the same as cast-in-place walls built removable forms; however, the foam forms are left in place. Structurally, the foam does not add to the engineered wall strength. The design of reinforced concrete walls is governed by the ACI-318 Building Code Requirements for Reinforced Concrete, published by the American Concrete Institute (ACI). For flat wall ICFs, ACI-318 chapter 14 governs the design of the wall. For grid/waffle ICF walls, ACI-318 section 14.4 and 22.6 can be applied to the wall sections with other than solid, rectangular cross sections. For post-and-beam ICF walls, ACI-318 chapter 10 can be applied for the flexure and axial loads of the frame design. However, each manufacturer provides their own structural calculations and design requirements, based on the ACI-318 and other building

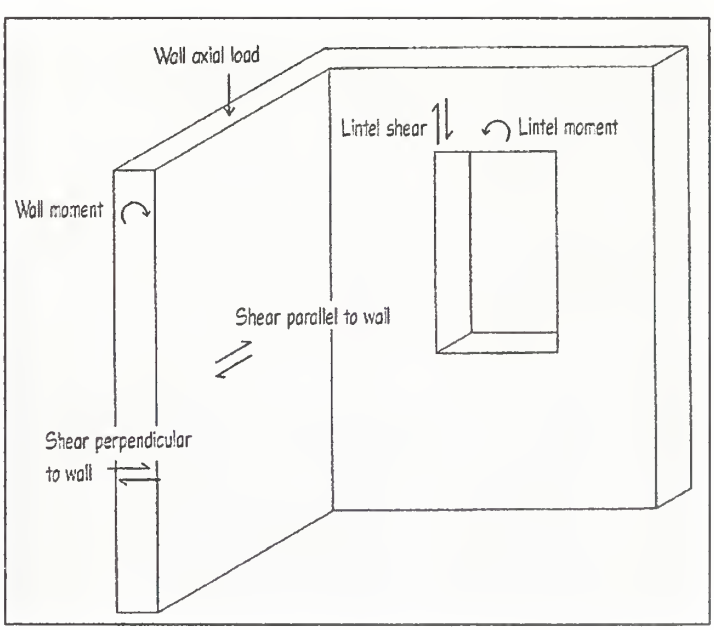


Figure 2-9. Forces Analyzed During ICF Wall Design [VanderWerf et al., 1997]

code requirements.

For the design of ICF walls, Figure 2-9 shows the typical forces analyzed in ICF engineering. Some of the variables that an engineer can vary include the concrete compressive strength, concrete wall thickness, wall height and length, and vertical and horizontal steel reinforcement (size, spacing & number of bars, tensile strength, placement). Concrete is usually specified at 3000 psi compressive strength. The geometry of the ICF forms typically dictates the thickness of the concrete walls, either 6 or 8 inches. For a non-bearing wall, the minimum thickness is 4 inches [ACI 318, 1989]. Reinforcement steel is either specified as 40 or 60 ksi (grade 40 or 60) steel, and the arrangement, including thickness of diameters, number of bars, and location in walls allow designers flexibility in designing ICF walls.

Reinforced concrete design procedures of ICF walls include analysis and calculation of minimum reinforcement, flexure and axial loads for grid walls, empirical design method for flat ICF walls, compression members, slenderness, shear, lintel bending, and lintel shear. The reinforced concrete walls

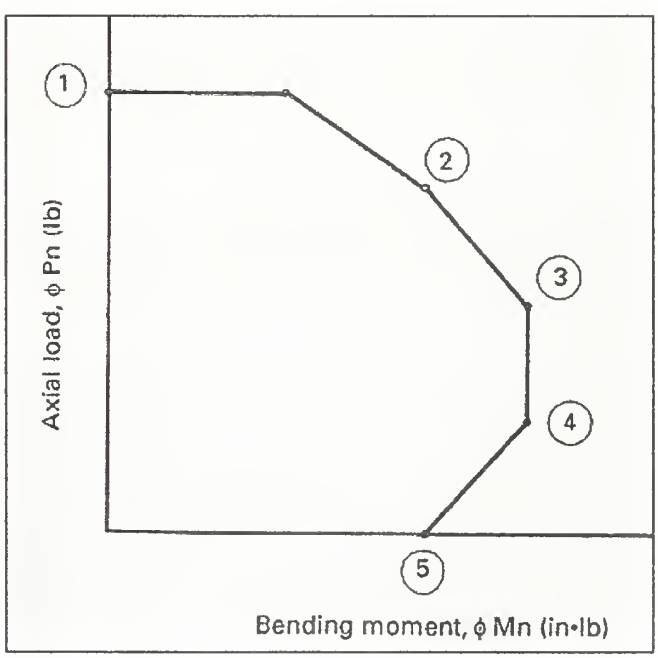


Figure 2-10. Transition Stages on Interaction Diagram [VanderWerf et al., 1997]

must be designed for the combined effects of axial load and bending moment, which are represented by the axial load-bending moment interaction diagram shown in Figure 2-10. The five stages in the interaction diagram that must be considered include:

1. Pure compression (no bending moment)
2. Stress in reinforcement closest to tension face = 0
3. Stress in reinforcement closest to tension face = .5 times yield stress
4. Balanced point where reinforcement stress at tension face = yield stress
5. Pure bending (no axial load)

For residential design, the area of focus for engineers is between stages 4 and 5 of the interaction diagram since factored axial loads are typically below the balanced steel reinforcement ratio.

For the load design of a typical ICF system, the values in Table 2-2 can be used as an example [VanderWerf et al., 1997]

Variable	Assumed Value
Wind Load	25 psf
Roof Live Load	20 psf
Roof Dead Load	20 psf
Floor Live Load	40 psf
Floor Dead Load	10 psf
Vertical Reinforcement & Spacing	One #4 @ 24" oc
f'c (concrete compressive strength)	3000 psi
f"c (steel reinforcement tensile strength)	40 ksi

Table 2-2. Typical Load and Concrete/Steel Specifications [VanderWerf et. al., 1997]

Chapter 3. Comparisons Between ICF and Wood Frame Homes

Description of Main Case Studies.

The use of Insulating Concrete Forms is a new technology that does not have a significant amount of research compared to wood frame construction. In fact, only three detailed studies have been completed that compare ICFs to wood frame construction, and these studies are all less than 3 years old. These initial studies compare performance of the housing systems with respect to thermal and acoustic properties, costs of initial construction and energy costs, and other topics.

VanderWerf Energy Comparisons of ICF Versus Wood Frame Homes. Dr. Peter A. VanderWerf, Ph.D., compiled research data from 29 ICF homes and 29 wood frame homes across the United States and Canada, as shown in Figure 3-1. The energy consumption was recorded for each home, with the energy consumption further divided into heating, cooling, and nonconditioning consumption. Energy consumption data and prices were acquired from utility companies and fuel vendors. The data for each home was then normalized so that all comparisons were made based on houses of similar size and composition, with the home adjustments for data comparison including the following: [VanderWerf, 1998]

- 2100 SF of conditioned space
- Two stories above grade and full basement foundation
- Homes housed 3 regular occupants
- Average day and night thermostat setting of 69°F in winter and 74°F in summer
- Heating equipment 100% efficient

- Cooling equipment 285% efficient

Adjustment factors and relationship equations were developed for size of home, thermostat settings, number of occupants, and HVAC efficiency.

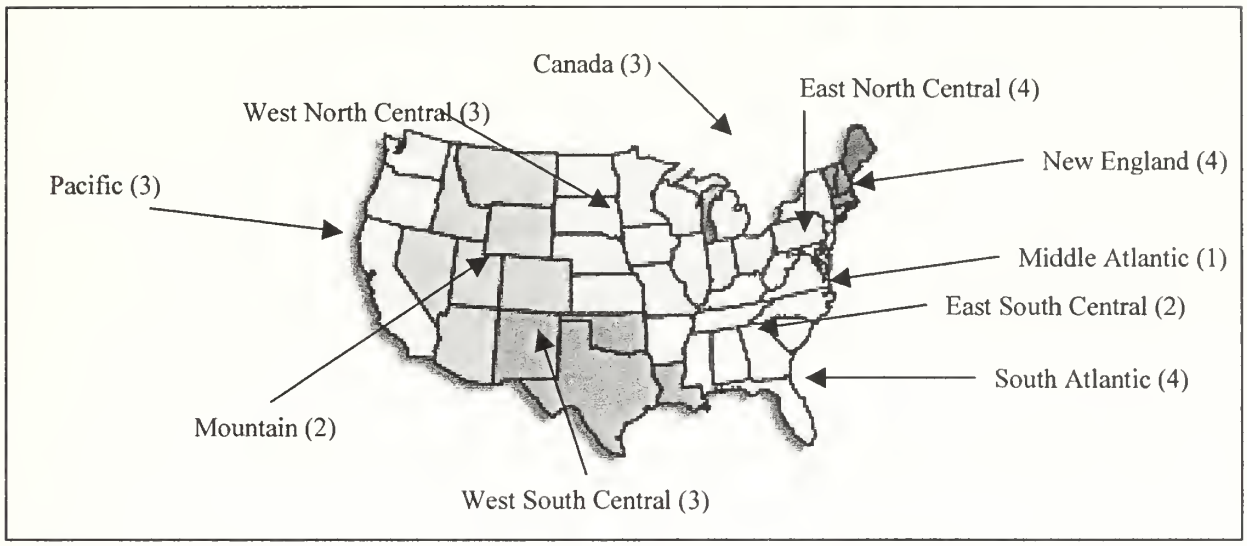


Figure 3-1. Distribution of Homes for VanderWerf Energy Study between ICF and Wood Frame Houses (Number of Pairs of Homes Compared in Parenthesis)

Detailed interviews were also conducted with homeowners, who cited reasons for liking and disliking ICF and frame homes.

NAHB Study of Installed Cost, Acoustic, and Thermal Performance. The NAHB Research Center compared three homes in Chestertown, Maryland with identical floor plans, but the homes were constructed with an ICF plank system, an ICF block system, and a conventional 2x4 lumber construction. The study compared labor costs for construction, acoustic sound tests of the exterior walls, and thermal properties of the three homes. A primary objective of the study was to answer some of the questions regarding the in-place costs of ICF homes compared to typical wood frame homes.

Figure 3-2 includes the 1098 SF floor plan used for the three homes. For the two ICF homes, ICFs were used for above-grade exterior walls and foundation walls, while the wood framed home was constructed with 2x4 wall stud framing, sheathed with oriented-strand board (OSB), insulated with R-13 fiberglass batt insulation in wall cavities, and included a concrete masonry (CMU) foundations. [NAHB, December 1998]

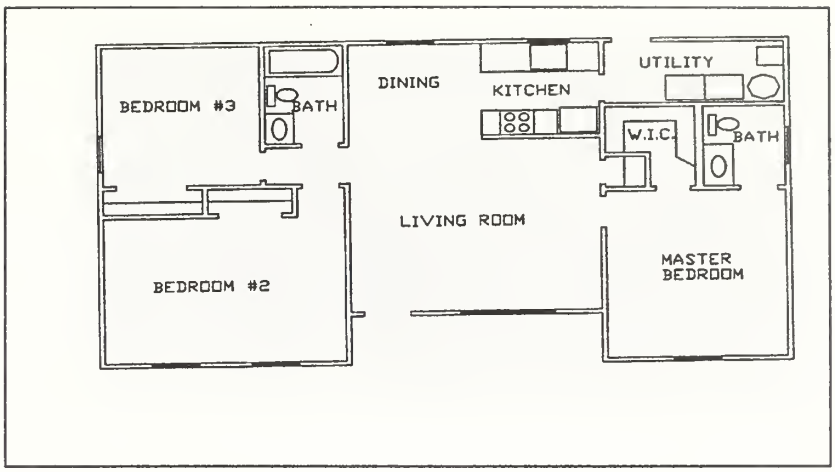


Figure 3-2. Floor Plan for Three Homes in Chestertown, Maryland Used for NAHB Research Center Study [NAHB, December 1998]

<u>NAHB Study of ICF Residential Construction-Demonstration Homes</u>. The NAHB Research Center evaluated the design, building code, construction, and marketing issues faced by an ICF builder in the United States. Four ICF demonstration homes were constructed in Virginia Beach, Virginia; Austin, Texas; Sioux City, Iowa; and Chestertown, Maryland. Initial observations were taken during the construction process, and thermal and acoustic testing were conducted after construction to assess the performance. Additionally, detailed interviews with the homeowners were conducted to assess impressions of design, construction, thermal comfort,

sound comfort, and overall satisfaction. Builders were interviewed regarding the construction process and construction costs, which were compared to wood frame housing for similar homes. [NAHB, July 1997]

Construction of ICF Home

One of the major issues facing ICF construction is the fact that the use of Insulating Concrete Forms are not universally covered under model building codes; several manufacturers have gained proprietary approval for their systems from BOCA, SBBCI, and ICBO. However, this is not usually enough to avoid preparing a full set of plans and specifications for local building approval. The Evaluation Protocol for the use of ICFs discussed in Chapter 1 could make the construction approval process significantly easier if it can obtain inclusion into the three model building codes, CABO, and their eventual successor, the International Building Code. [NAHB, July 1997]

Constructibility Design Issues. The main constructibility issues for a contractor include meeting the minimum reinforcing steel requirements (as required by ACI) for walls and lintels, local fire code requirements for fire separation and flammability, termite protection requirements for below the ground surface (foam insulation not currently allowed by SCCCI under ground), moisture control requirements as specified by CABO One-and-Two-Family Dwelling Code, seismic resistance requirements, and wind resistance requirements. The Insulating Concrete Form Association has published

twelve proposals to overcome the current foam insulation restriction below grade in heavy termite-infested areas, with the proposals including chemical sprays, foam barriers, soil treatment, and colony elimination systems (where poison is transported back to colony to kill the infestation). [NAHB, July 1997]

Construction Practices. Typical construction practices that will be discussed in this section include concrete placement and installation of the foundation. For an ICF home, the concrete usually specified has a compressive strength of 2500-3000 psi, aggregate size of 3/8"-3/4", a 4-6" slump, and is considered a "Pump Mix", which is a high flow concrete that will move well through a 2" pump. This mix is much more workable than normal concrete used in housing with a compressive strength of 3000 psi, ¾" aggregate size, and a 4" slump. The better flowing mix better allows the concrete to fill more of the void spaces in the insulating concrete forms. Because of the insulating forms, the concrete can be placed in much colder temperatures than ACI specifies (10°F versus 50°F) due to the insulating effect of the forms. For foundations, several constructibility options available for a builder. For houses with crawl spaces or slab foundations, the ICF system can start on top of the poured footing, with the interior slab poured inside the exterior ICF wall; this provides good foundation insulation. For warmer climates, another method is to start the ICF system on edge of a

thickened slab. For basements, ICFs are a good choice for non-termite infested areas. [NAHB, July 1997]

ICF Versus Wood Framed Homes. The construction of an ICF home requires better planning than a wood framed home, due primarily to the permanence of the concrete walls once constructed. Additionally, most contractors, even new ICF contractors, are much better familiar with wood frame construction and can more easily make on-site changes. For an ICF home, accurately pre-determining the location of utility penetrations, exterior and interior finishes, and roof and wall attachment details are very important, as changes can be very expensive after the ICF walls are set. For utility connections, using a sleeved penetration is recommended for an ICF wall. Good planning is required for doors and windows, as the window and door spaces must be well braced when the wall is placed. The thickness of the ICF walls also require proactive planning for doors and windows, as the depth must be considered; this is usually not much of an issue with wood framed homes. For ICF homes, the corner details are usually specified or pre-fabricated. [NAHB, July 1997]

Construction Costs

Construction data was compiled for 6 ICF and Wood Frame homes in Texas, Virginia, Maryland, and Iowa. The compiled data included labor hours, and labor and material costs. During ICF construction, the insulation is included

in the wall forming; however, in wood frame construction, the insulation is completed after the walls are erected. The labor costs for wood frame construction include the cost of installing fiberglass batt insulation.

Figures 3-3 through 3-8 show cost comparisons between six houses constructed with different ICF systems versus wood frame construction. Figures 3-3 and 3-4 compare labor costs between ICF and wood frame construction. Figures 3-5 and 3-6 compare material costs between ICF and wood frame construction. Figures 3-7 and 3-8 compare total cost between ICF and wood frame construction.

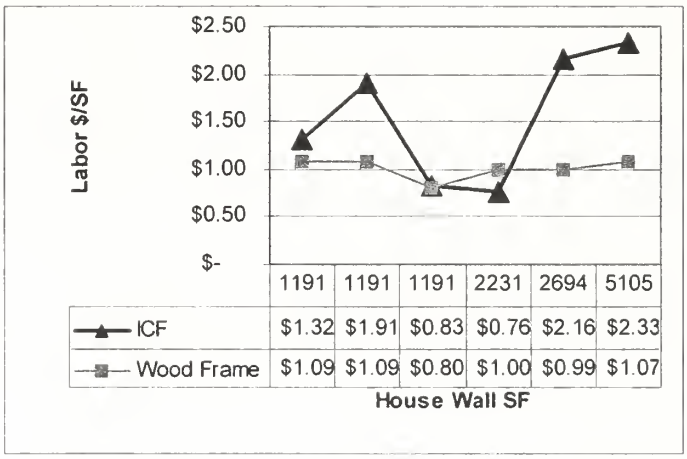


Figure 3-3. ICF vs Wood Frame: Labor Cost versus Wall SF [NAHB, Jul. 1997 & Dec. 1998]

Labor Cost. From Figures 3-3 and 3-4, the labor estimates for ICF homes do not have a definable pattern. These types of variations are possible depending on the experience of the crew and

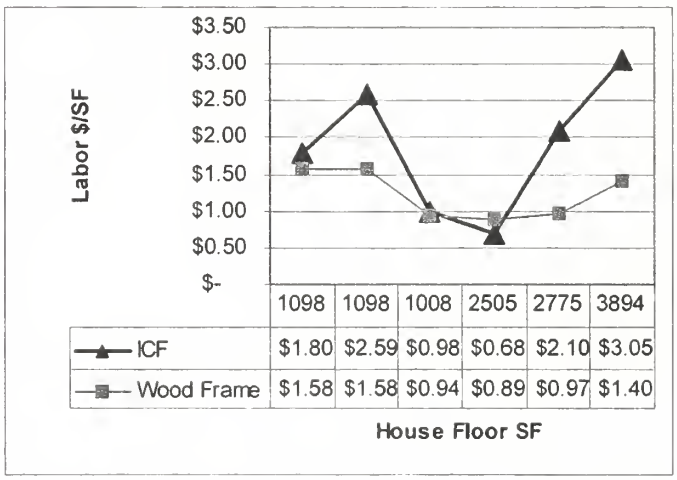


Figure 3-4. ICF vs Wood Frame: Labor Cost versus Floor SF [NAHB, Jul. 1997 & Dec. 1998]

how many times they have built ICF homes. Builders normally need at least three homes to get over the "learning curve" for productivity. Additionally, the complexity of the ICF walls in a home can have a significant bearing on cost. The larger houses would have higher rates due to their complexity, i.e., more architectural walls, higher walls (which would increase the price by requiring additional scaffolding/ bracing). However, the labor cost of wood frame construction was fairly stable, with minimal fluctuation between house sizes and generally less than ICF construction, up to 50 percent less.

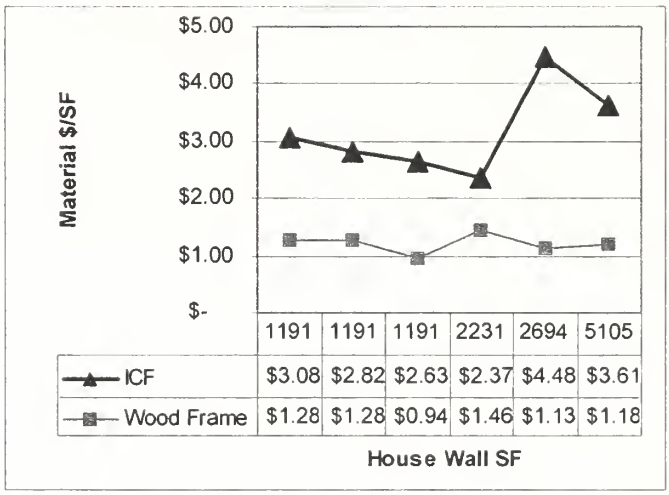


Figure 3-5. ICF vs. Wood Frame: Material Cost versus Wall SF [NAHB, Jul. 1997 & Dec. 1998]

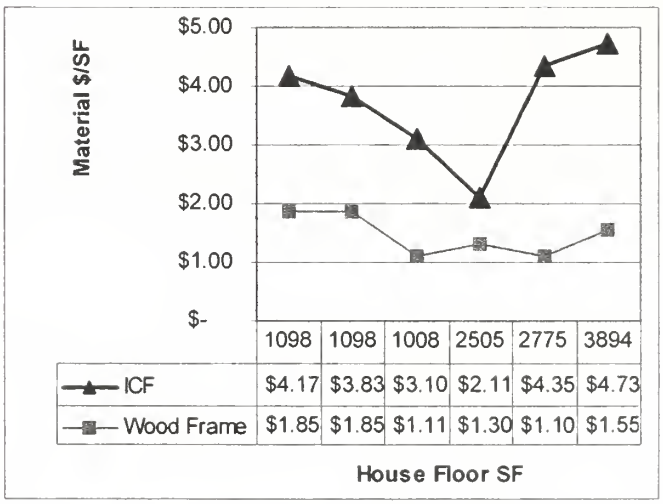


Figure 3-6. ICF vs. Wood Frame: Material Cost versus Floor SF [NAHB, Jul. 1997 & Dec. 1998]

Material Cost.

Material costs as shown in Figures 3-5 and 3-6 for ICFs were much higher than wood frame construction, ranging from 62 to 295 percent higher, with an average of 167 percent higher. The two

main factors attributing to the higher costs include the cost of the insulating concrete forms and the concrete.

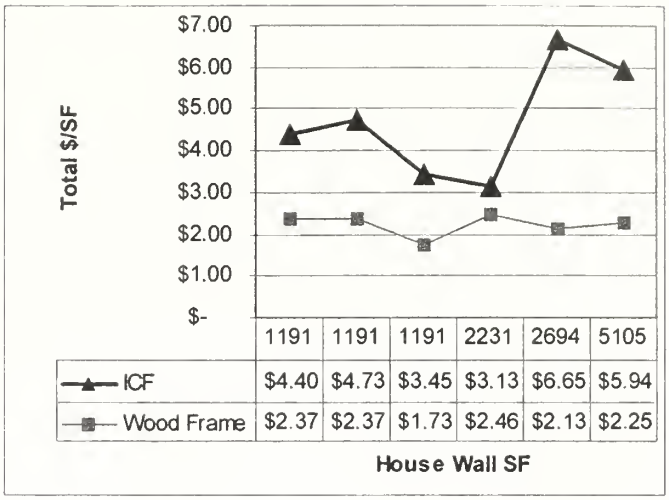


Figure 3-7. ICF vs. Wood Frame: Total Cost of Wall SF [NAHB, Jul. 1997 & Dec. 1998]

<u>Total Cost</u>. The total cost of installing ICF foundations and walls was more than double the cost of wood frame construction, with an average of 115 percent difference. Despite the cost of installing ICFs was double the cost of wood frame construction, the actual additional cost to the house selling price amounts to an average increase of 2-4 percent.

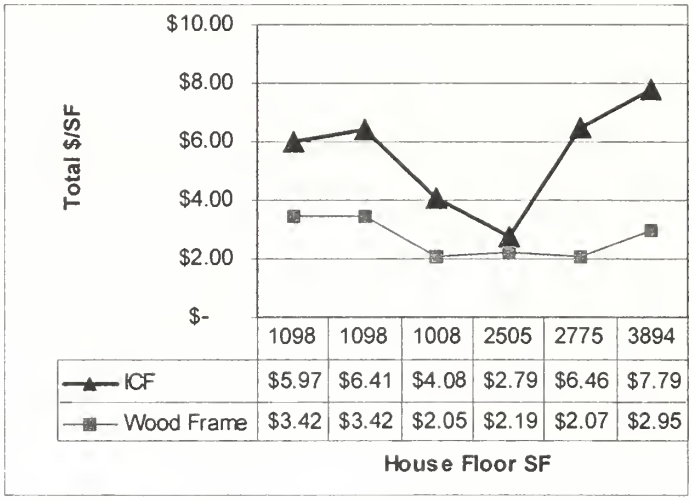


Figure 3-8. ICF vs. Wood Frame: Total Cost of Floor SF [NAHB, Jul. 1997 & Dec. 1998]

<u>Construction Time</u>. The time to construct the ICF and wood frame homes were also measured. The ICF foundation walls were completed in less time than wood frame homes, which where the foundations were made with CMU block. The wood frame above-grade walls were erected faster than the ICF walls, but overall,

the time to construct ICF walls and foundation was comparable to wood frame house construction.

In order to speed up production of ICF walls, the following measures can be implemented: Increase the height of ICF block courses, produce ICF block heights that correspond to horizontal rebar spacing, reduce rebar requirements, and use half height blocks instead of cutting blocks in half.

Effect of Price Fluctuations. Figures 3-9 and 3-10 compare the total cost of ICF versus wood frame construction if the price of ICF construction decreased 25 percent and if the cost of wood frame construction increased 25 percent. Any major decreases in total ICF cost would be attributed to a major decrease in cost of ICF materials and smaller decreases in labor and concrete costs. A major increase in the cost of wood frame construction would

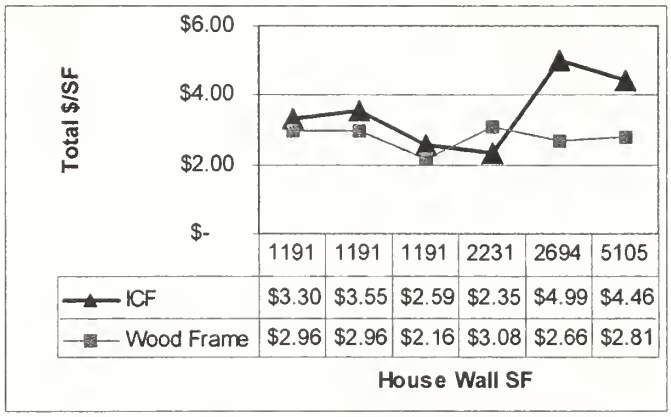


Figure 3-9. ICF vs. Wood Frame: Total Wall Cost for 25% ICF Cost Decrease and 25% Wood Increase [NAHB, Jul. 1997 & Dec. 1998]

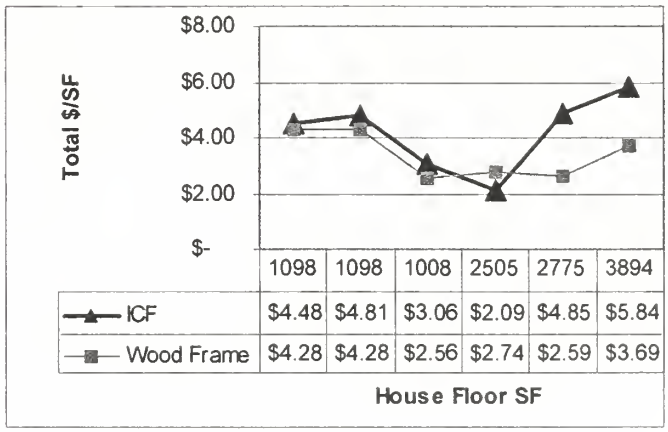


Figure 3-10. ICF vs. Wood Frame: Total Floor Cost for 25% ICF Cost Decrease and 25% Wood Increase [NAHB, Jul. 1997 & Dec. 1998]

have to be primarily due to an inflated price of lumber due to some lumber shortage. The bottom line is that normal, minor fluctuations in the price of concrete, lumber, and ICFs will not substantially change the large price difference between ICF and wood frame construction.

Proponents of ICFs argue that although the capital cost of ICF installation is high, the net cost is much lower, and either comparable or surpassing wood frame construction. Figure 3-11 shows an example of the net cost of wall construction. The energy effects and heating/cooling equipment impacts are discussed later in this chapter. Based on predicted energy efficiency of ICFs, smaller heater and air conditioning units than for a conventional can be utilized for construction capital cost savings. Ultimately, an average of $2/SF is added to the cost of conventional construction, with a range from $0.25 to $3.25. For example, a 2000 SF house built with conventional wood framing that costs $75/SF or $150,000 would cost $77/SF or $154,000 building with ICFs.

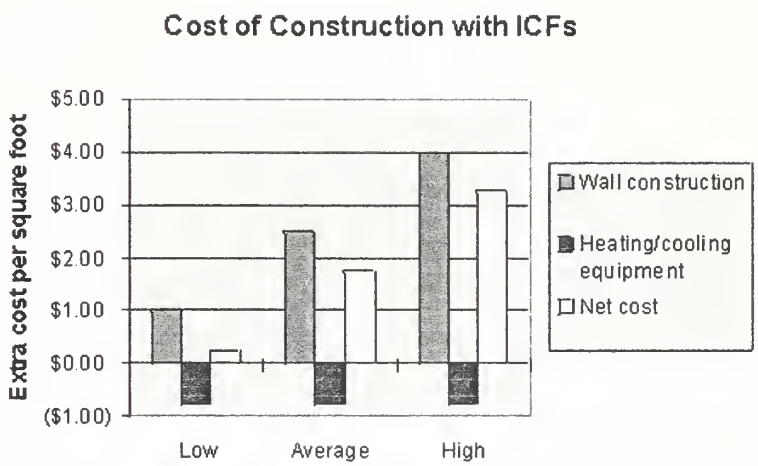


Figure 3-11. Example of Net Cost Savings due to ICF Construction [PCA, 2000]

Fire Resistance

Fire Resistance Requirements. The risk of fire is a concern for all residential housing, and the performance of exterior walls is measured by four scenarios: [VanderWerf et al., 1997]

- The walls will fail structurally, which could cause severe property damage and personal injury. ASTM E119 requires a "fire wall test" to determine structural suitability and performance during a fire.
- The walls will allow fire to pass through the wall, which would be a concern for outside fires and/or fires through an adjacent building such as adjoining condos, etc. The fire wall test also addresses the wall's performance for this criteria.
- The materials in the wall might burn, adding fuel to the fire. The potential flammable material is the foam/Styrofoam in the ICFs.
- The materials could emit fumes when subjected to fire that could asphyxiate or incapacitate occupants. Foam can produce more carbon smoke than wood framing during a fire, but are under code-allowed maximum levels for insulation products.

Fire Performance. ICFs perform better than wood framing in fires because the walls are concrete, which does not burn or soften or break down during a typical house fire. Fire wall tests, where the walls were heated with gas flames at 2000 degrees Fahrenheit for 4 hours, were conducted to compare ICF and wood walls. Wood frame walls earned a fire rating range

from 0.75 to 1.0 hours, while the fire rating for ICF walls ranged from 2.0 to 4.0 hours. The Fire Rating comparison is shown in Figure 3-12.

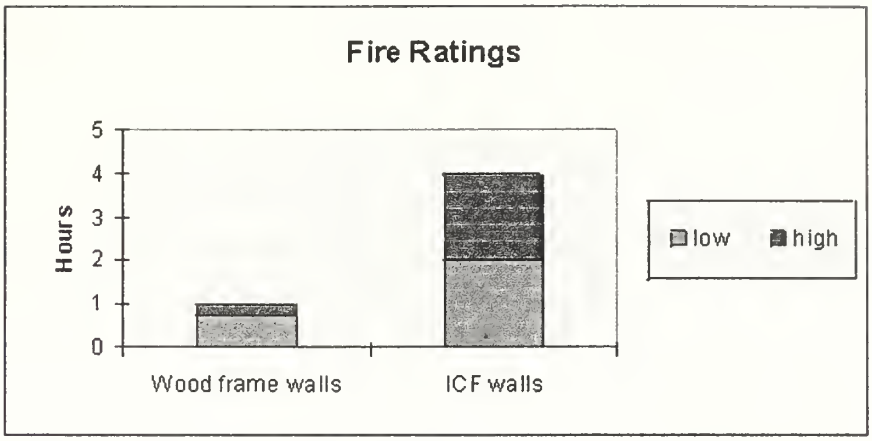


Figure 3-12. Fire Rating Performance of ICF vs. Wood Frame Walls [PCA, 2000]

Additionally, the flame spread is much lower with ICFs than wood walls. The Steiner Tunnel Test, conducted by lining identical tunnels with ICFs and wood construction, showed that the flame spread index for ICFs is less than 1/5 of wood construction, as shown in Figure 3-13. The foams in ICFs are manufactured with flame-retardants that melt, not burn, when a flame is applied.

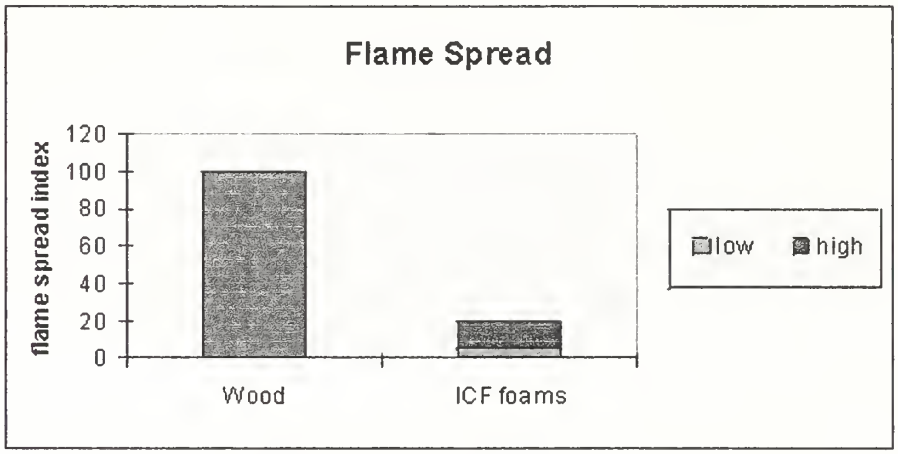


Figure 3-13. Flame Spread Performance of ICF versus Wood [PCA, 2000]

Acoustical Properties

One of the benefits of ICF walls includes a significant sound reduction from wood frame walls. Figure 3-14 shows the difference between the amount of sound allowed through the ICF walls, which include the concrete and foam insulation layers, and the wood frame walls. The ICF walls restrict more sound through the walls than wood frame walls.

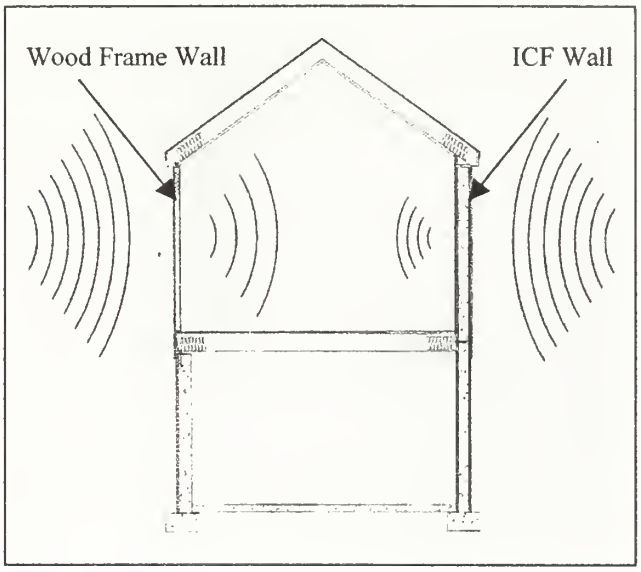


Figure 3-14. Sound Attenuation of Wood Frame vs ICF Wall [VanderWerf et al., 1997]

The measure of the sound through the mediums is referred to as the sound transmission class (STC), which is measured by recording the fraction of generated sounds over a range of frequencies through the wall. Conventional wood frame walls have measured an STC rating of 36, which means approximately that the sounds were "audible but not intelligible", while various ICF walls have measured between 44 and 58, which are described as between "must strain to hear" to "inaudible". [VanderWerf et al, 1997] However, these tests do not include effects of windows and doors on the real rating for a normal house.

A study by the Portland Cement Association showed in Figure 3-15 that sound can be reduced in ICF walls up to 8 times a conventional wood-framed house. The bottom line is that ICF walls perform better, than wood frame walls, but each house would have to be tested to obtain the true STC rating, which would take into account doors, windows, consistency of insulation, thickness of walls and insulation for each house, etc.

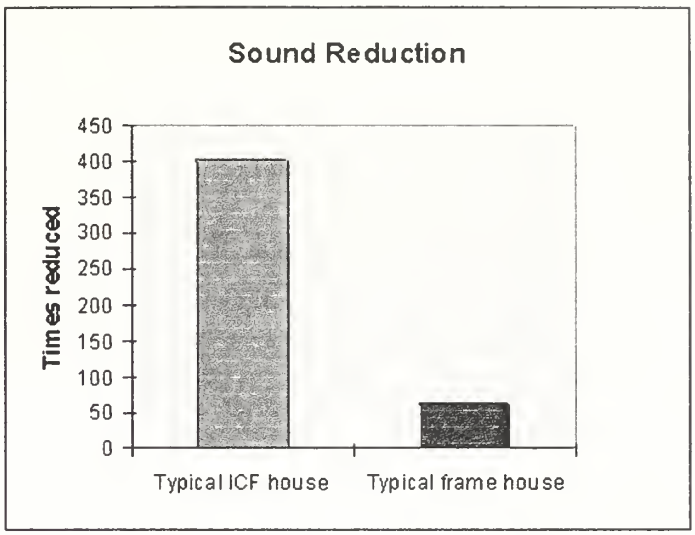


Figure 3-15. Sound Reduction Comparison between ICF and Wood Frame House [PCA, 20001

Durability and Strength of Walls

ICF walls, which are concrete walls with foam insulation, are structurally much stronger than wood frame walls. Concrete and/or CMU house construction is required in most areas with high hurricane and typhoon risks, as concrete walls resist the effects of storm damage and potential missile damage much more effectively than wood-framed construction. To compare ICF versus wood and steel framed homes, missile debris tests were performed; with damage recorded as 2 x 4 stud missiles were projected at varying speeds into the walls. The four types of walls tested included: [PBR, October 1, 1998]

- Wood Frame: The wood frame walls were built with 5/8" gypsum board interior finish, 2 x 4 wood studs at 16" o.c., 3-1/2" batt insulation, 3/4" plywood sheathing, and brick and vinyl siding exterior finishes.
- Steel Frame: These walls were built with 5/8" gypsum board interior finish, steel studs at 16" o.c., 3-1/2" batt insulation, 3/4" plywood sheathing, and vinyl siding and synthetic stucco exterior finishes.
- Concrete: These walls were built with 6" thick reinforced concrete with #4 vertical reinforcing bars at 12" o.c. and no exterior finishes.

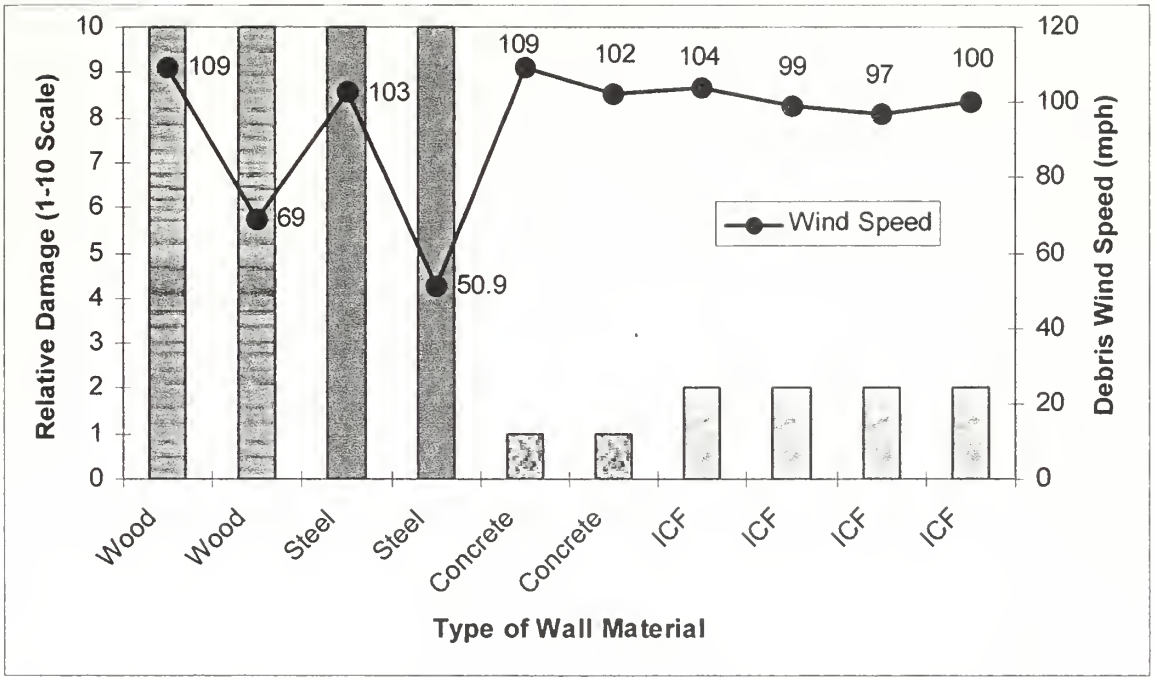


Figure 3-16. Relative Damage by Type of Wall Material and Debris Speed [PBF, October 1998]

- ICF: These walls were built with block and panel ICF foam forms, 4 and 6 inches of concrete, #4 vertical reinforcing bars, and vinyl siding, brick veneer, and synthetic stucco for exterior finishes.

Figure 3-16 graphically shows the relative performance of each wall when subjected to missile debris at different speeds. The wood and steel frame walls scored a relative damage of 10 on a scale of 1 to 10, meaning that the missile debris completely perforated the walls with minimal to no damage to the missiles. Concrete walls scored a relative score of 1 on a scale of 1 to 10, with the debris causing no cracking, front face scabbing, or back face spalling of the concrete. The ICF walls scored 2 out of 10, with the only damage including the debris penetrating and cracking the exterior finishes and outer foam insulation.

Chapter 4. Energy Comparisons

Introduction

This chapter focuses on the energy comparisons between ICF and wood framed construction. The first part of this chapter focuses on the thermal properties of ICF and wood frame walls that affect the material's abilities to store and resist heat transfer. Later in this chapter, the cost savings potential of ICF versus wood framed construction will be presented. ICF proponents claim that while the capital cost of an ICF system adds 2-4 percent to the cost of a home over wood framing, the life cycle costs including energy savings make the ICF system a better economic choice than wood frame construction.

Thermal Mass

The thermal mass or thermal flywheel is an advantage of ICF systems over wood frame systems. Structures with heavy materials for the exterior will consume less energy to heat or cool than comparably insulated structures, with the difference attributed to the additional thermal mass of the ICF walls.

The magnitude of thermal mass is dependent on the heat capacity of the walls, local climate temperature changes, and thermal resistance of the walls. The heat capacity of a wall is the amount of energy required to raise the raise a unit area of the wall by a unit temperature [Btu/(sq ft * °F)]. As

Consistency of Insulation

ICF walls include the foam and concrete as the insulating materials and, therefore, more fully cover the walls when the walls are formed. In wood frame construction, insulation is added after the frame is erected. Typically, there are gaps along the studs and between insulation pieces. ICFs, consequently, have fewer cold spots than wood framed construction and provide better consistency. As shown in Figure 4-2, the percent of wall area covered is about 95 percent for ICF walls compared with 75 percent for wood frame walls. Ultimately, the more consistent coverage of insulation will mean some savings in energy costs.

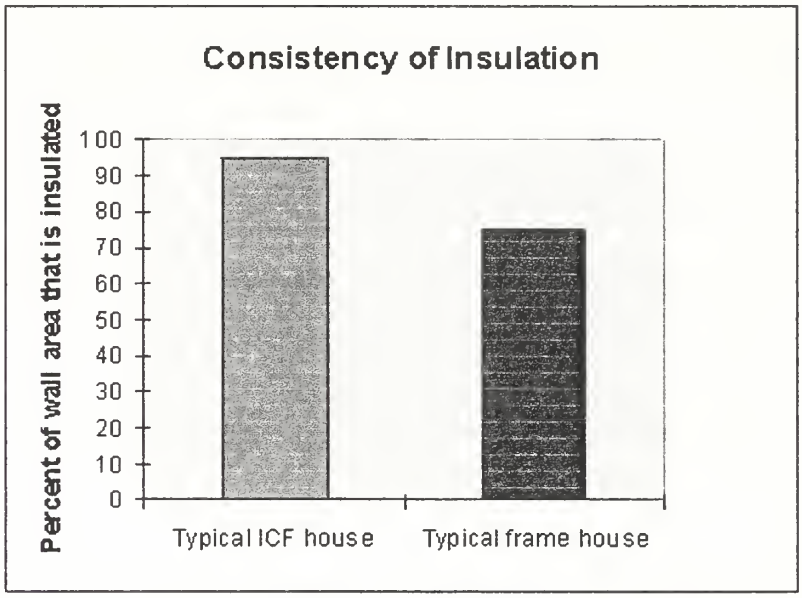


Figure 4-2. Consistency of Insulation Coverage between ICF and Wood Frame Walls [PCA, 2000]

Air Infiltration

ICF walls perform better than wood walls regarding air infiltration. The interlocking foam blocks or panels and solid concrete significantly reduce the air drafts. As shown in Figure 4-3, a typical ICF house will allow only

about 0.18 air changes per hour, while a wood house will allow almost 0.5 air changes per hour.

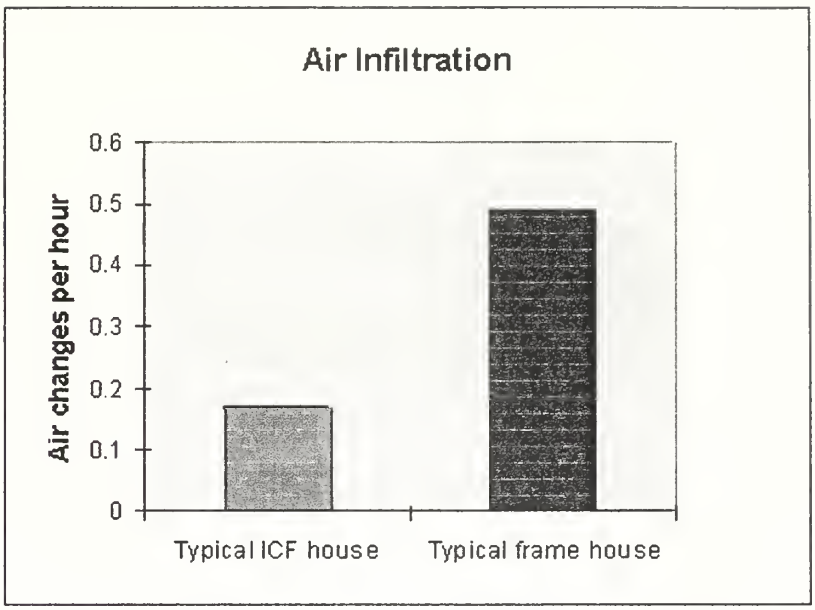


Figure 4-3. Air Infiltration Comparison between ICF and Wood Frame Walls [PCA, 2000}

R-Values

The R-value, or thermal resistance, is the most widely used label of a predicted performance for a wall's thermal resistance. The thermal resistance is the material system's resistance to the conduction of heat from one side of the medium to the other, and is measured in h * sq ft * Δ°F/Btu. One of the most used tests for determining a wall's thermal resistance is a "guarded hot box", where a required amount of heat energy is added to maintain a temperature on the other side of the wall. The R-value for wood frame construction is typically in the 15-19 range. For ICF walls, the R-values are significantly higher in the 23-35 range.

Sources of Energy Loss

Energy loss in a house occurs from several sources, of which the walls are one component. Figure 4-4 shows that over half of a home's energy loss is attributed to walls and air infiltration.

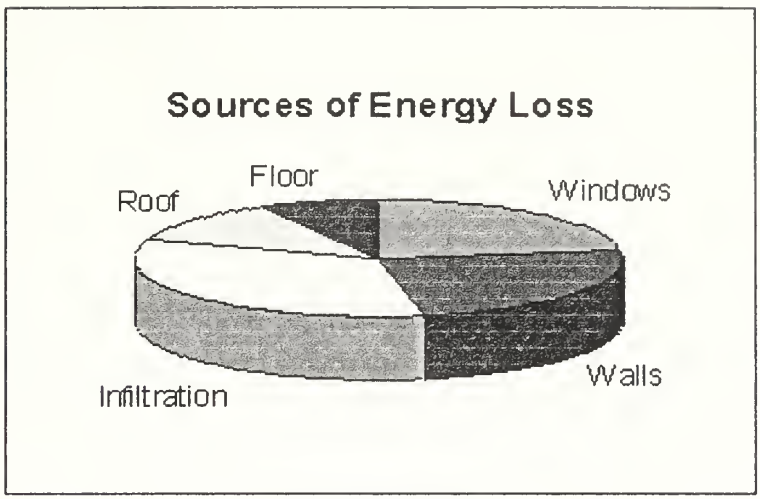


Figure 4-4. Sources of Energy Loss in Typical House [PCA, 2000]

An ICF wall contributes in several areas to reducing the amount of energy. Figure 4-5 shows that ICF systems aid in wall loss and infiltration reduction over wood frame walls, plus the added contribution of the concrete wall thermal mass. These savings in energy use can reach 30-45 percent.

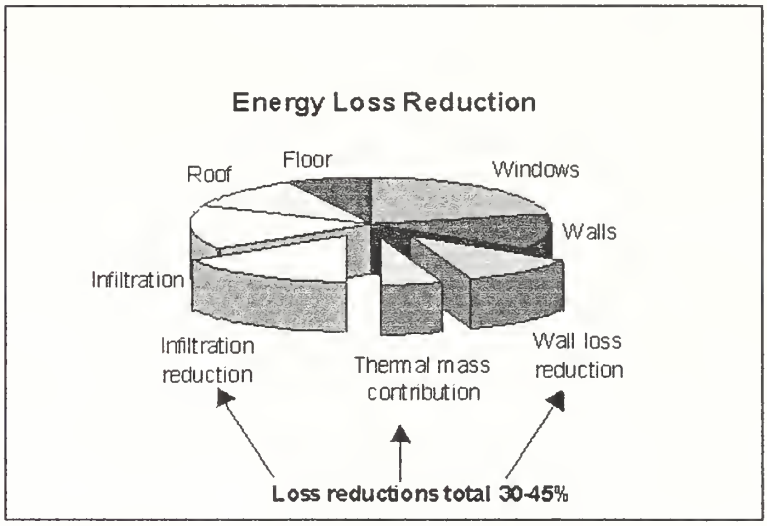


Figure 4-5. ICF Contribution to Energy Loss Reduction [PCA, 2000]

Energy Savings by Climate and Location

The first published energy consumption and cost savings data between ICF and wood frame housing has been within the past couple years, as the ICF industry is fairly new. The most important effect in total energy savings is caused by the local climate and the number of heating and cooling degree days. Based on thermal mass as discussed previously, an ICF home will have the lowest costs in the southern United States due to smaller fluctuation of temperatures above and below a typical indoor temperature of 68 degrees in the winter and 76 degrees in the summer. However, energy savings would be a larger dollar amount in areas where the heating and cooling degree-days were higher, such as the northern states and Canada. This section examines that presumption.

VanderWerf's study ultimately produced a table of data representing an annual estimate of energy savings by house size and location, with Minneapolis, Minnesota selected for a cold climate; St. Louis, Missouri selected for a moderate climate; and Dallas, Texas for a warm climate. Figure 4-6 shows

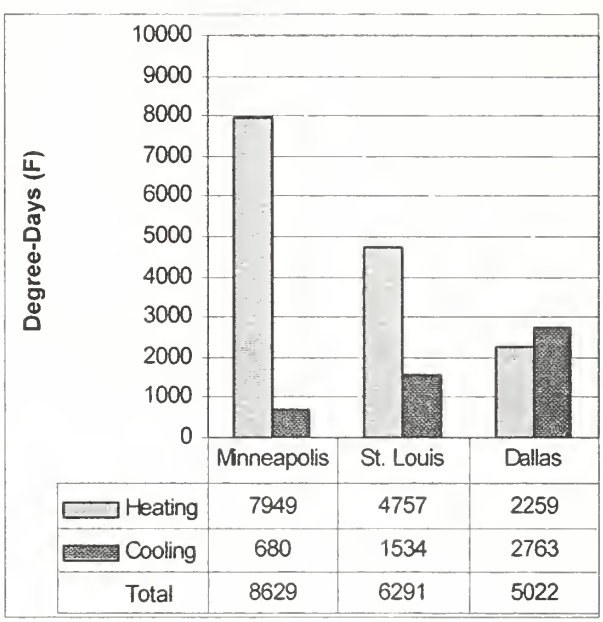


Figure 4-6. Heating and Cooling Degree-Days for Cold, Moderate, and Warm Climates [Buttle & Tuttle, 2000]

the number of heating and cooling degree days, respectively, for cold, moderate, and warm climates. [Buttle and Tuttle, 2000] Heating degree-days are defined as the cumulative number of degrees in the year by which the mean temperature falls below 65°F. Conversely, cooling degree-days are defined as the number of degrees in the year by which the mean temperature rises above 65°F.

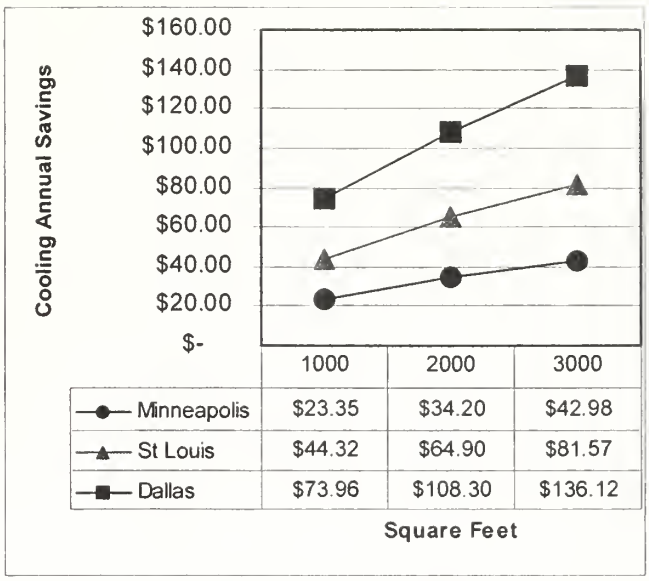


Figure 4-7. Annual Cooling Savings in Various Climates [VanderWerf, 1998]

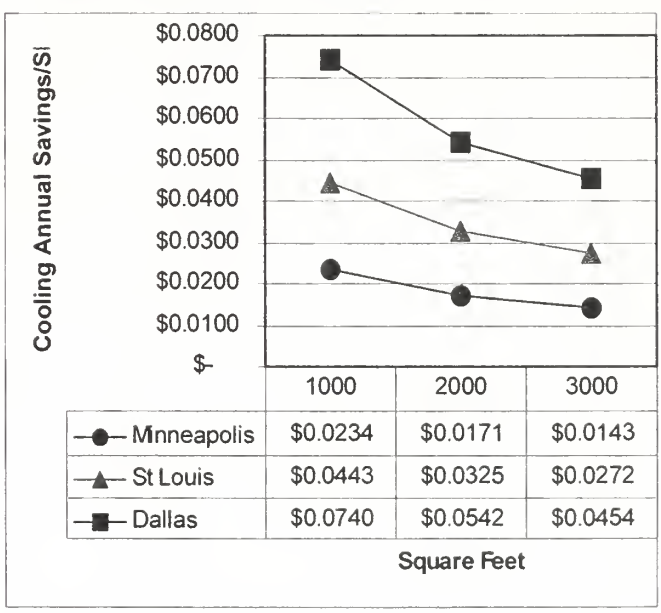


Figure 4-8. Annual Savings Per Square Foot for Various Climates [VanderWerf, 1998]

Cooling Savings. Relationships were examined between the climate, the annual savings due to heating and cooling costs, total costs, house size, and heating and cooling degree-days. Figure 4-7 looks at the relationship between annual cooling savings versus house size in a cold, moderate, and

warm climate. The cooling savings were about three times more in Dallas than Minnesota, which could be expected. Figure 4-8 shows the cooling annual savings per square foot of house. The greatest savings occur in smaller house size and decrease as the house size gets larger.

Heating Savings.

Figure 4-9 looks at the relationship between the heating annual savings and the house size in the three climates. As would be expected, the total savings were greatest in Minneapolis, with more heating costs incurred.

Figure 4-10 shows the relationship between the savings per floor size and size of the house in three climates. As with the

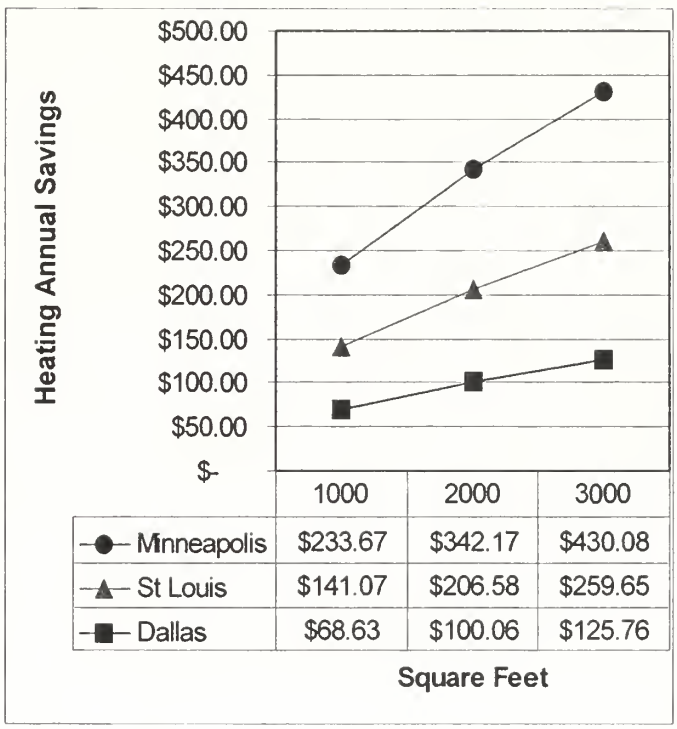


Figure 4-9. Annual Heating Savings in Various Climates [VanderWerf, 1998]

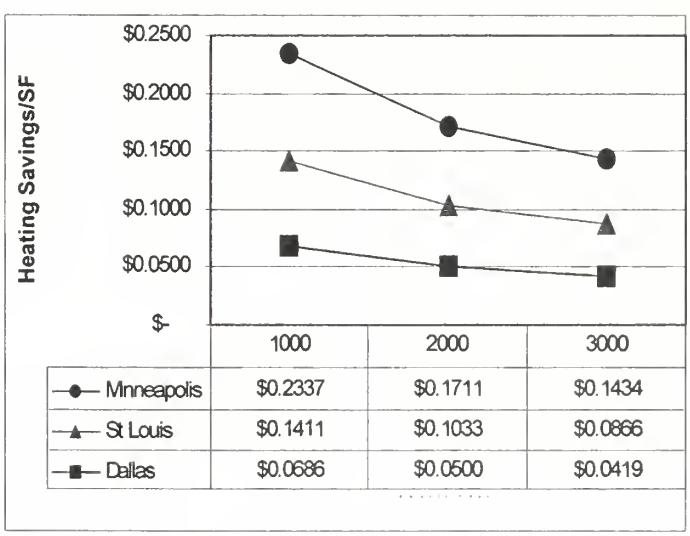


Figure 4-10. Heating Savings Per SF of House Size in Various Climates [VanderWerf, 1998]

cooling savings, the largest savings per square foot of house size were realized with a smaller house size, and decreased as the house sized increased. The savings were over 3½ times greater in the cold climate over the warm climate.

Total Annual Savings.

Total annual energy cost savings, including heating and cooling, were closer overall, with savings of 44 percent in a cold climate versus a warm climate. Figure 4-11 shows the relationship between total annual energy savings and house size for three climates.

Figure 4-11 shows the relationship between total energy savings per square foot of house size for three climates. As expected, Minnesota, with the highest amount of savings, had the greatest savings per house

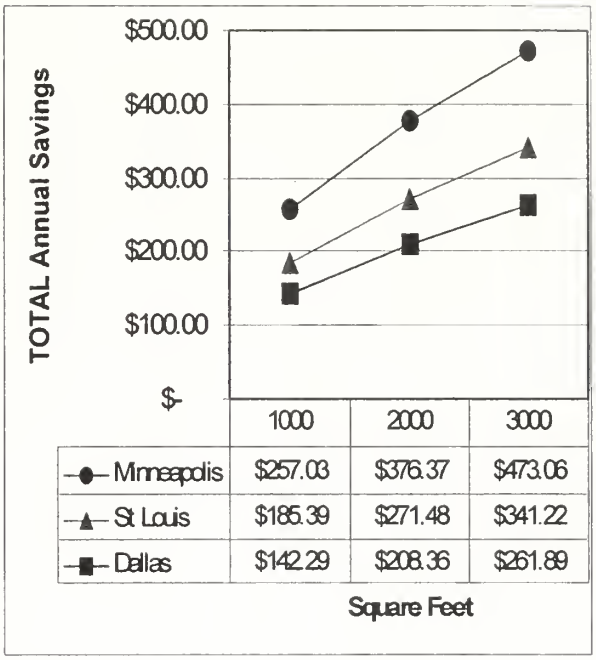


Figure 4-11. Total Annual Energy Savings in Various Climates [VanderWerf, 1998]

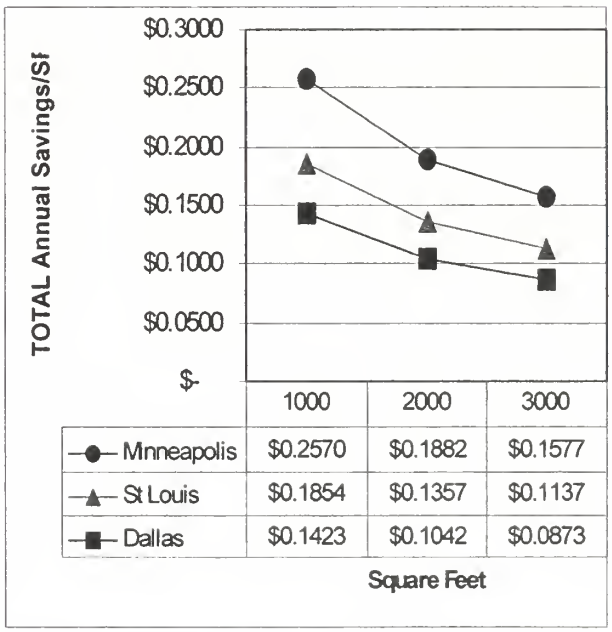
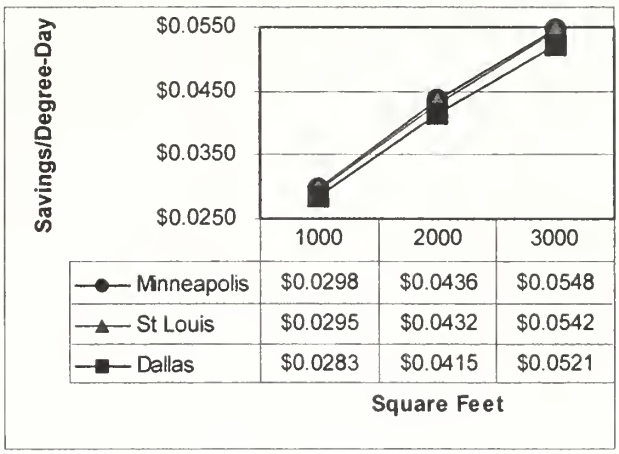


Figure 4-12. Total Annual Savings Per SF of House Size in Various Climates [VanderWerf, 1998]

area.

The relationships between absolute savings between heating, cooling, and total costs were established between costs and house size, but the relationship between the total savings and the total number of heating and cooling degree-days was not identified. The direct correlation between total energy heating and cooling savings is established in Figure 4-13 by dividing the total costs from Figure 4-11 by the total heating and cooling degree days in Figure 4-6. Figure 4-13 is significant because the total savings realized are directly related to the total number of heating and cooling degree-days for an area. Therefore, the maximum energy savings for construction of an ICF house will be realized in a very cold climate. The savings in energy are attributed to the thermal mass and additional R-value of the foam insulation. However, in terms of pure system performance, ICF purists would claim that the best performance is in a warm climate with fewer heating and cooling degrees by arguing theoretically that heating and air conditioning would not be needed in a



	1000	2000	3000
Minneapolis	$0.0298	$0.0436	$0.0548
St Louis	$0.0295	$0.0432	$0.0542
Dallas	$0.0283	$0.0415	$0.0521

Figure 4-13. Annual Total Energy Savings Per Total Cooling and Heating Degree-Days in Various Climates [VanderWerf, 1998]

house at all if the ambient air temperature averaged 65°F plus or minus ten degrees.

Life Cycle Costs

One of the selling points of ICF systems is that they eventually pay for themselves with the savings on energy bills. While there are several other selling points that ICF proponents would use, such as better sound resistance, fire resistance, strength, R value, the bottom line determinant for the typical American home buyer usually comes down to the capital cost, as that is the amount that the down payment and monthly payments are based. A secondary issue would be the energy savings and the payback period. Even if the payback period is considered, many homeowner may not own the home long enough to justify the payback. The VanderWerf study reported that up to 44 percent could be saved on heating consumption and 32 percent from cooling; however, these were the extreme of the ranges.

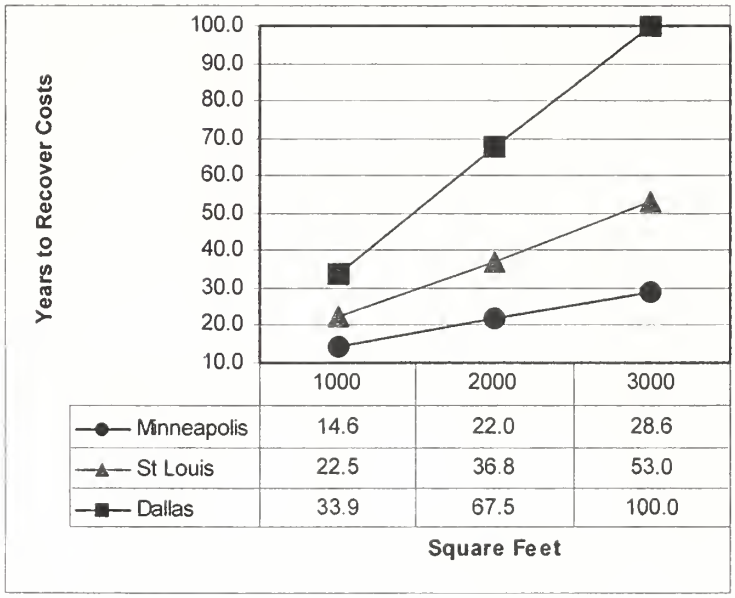
Figure 4-14 examines the number of years to recover the capital investment of the additional purchase price through the savings in energy. Assumptions made in the development of Figure 4-14 include a purchase price of $100/SF, so a 1000 SF house would cost $100,000. Additionally, the cost of buying an ICF home was estimated at 3% over the wood frame house, which is within the average 2-4% range. The rate of return used for the present worth analysis was a conservative 3% instead of 7%, a common rate

of return used in these types of analyses. Rates higher than 3% would create longer capital recover times than those shown in Figure 4-14. Equation 4-1 is the formula developed for the present worth analysis.

Wood Price = ICF Price – Savings (P/A, 3%, N Yrs) **[Equation 4-1]**

Where:
Wood Price = The new price of wood framed house at $100/SF
ICF Price = The new price of ICF House (Wood Price * 103%)
Savings = Annual Savings (From Figure 4-11)
(P/A, 3%, N) = Present Worth Given Annual Savings, 3% Rate of Return
N = The number of years where the extra cost of ICF home is amortized.

From Figure 4-14, the shortest payback time was 14 years for a 1000 SF house in a cold climate (Minnesota). Despite the savings in energy cost, the payback times were quite large, and for the average American homebuyer, the payback due to energy savings would probably not be an economic incentive to buy the house, as they will have sold it long before they realize the savings.



	1000	2000	3000
Minneapolis	14.6	22.0	28.6
St Louis	22.5	36.8	53.0
Dallas	33.9	67.5	100.0

Figure 4-14. Number of Years to Recover Energy Savings Based on 3% Rate of Return on Annual Savings

Chapter 5. Sources for ICF Products and Services

Internet Sources

The Internet is an outstanding resource for learning about the ICF construction techniques. One of the primary resources was an independent news and information website, http://www.icfweb.com. This website provided links to over 40 different companies that manufacture or install ICF systems, as well as trade publications and other links. Another very information website regarding news and technical information was a site sponsored by the Portland Cement Association at http://www.pcinews.com. Although the Portland Cement Association is a strong proponent for the use of concrete systems that included ICFs for home construction, they made prudent attempts to objectively collect data and present their research, with regards to how the surveys, tests, and observations were set up and executed. Other informative websites regarding the concrete construction industry include the following website listed below:

- www.pathnet.org - web site sponsored by HUD exploring innovative building technologies, including ICFs. Includes information on Installation, Benefits/Costs, Limitations, Code/Regulatory, and more.
- www.concretehomes.com - PCA's concrete homes site
- www.forms.org - the home of ICFA
- www.concretenetwork.com - general information about concrete
- www.oikos.com - web site dedicated to energy efficient construction and environmentally responsible building techniques
- www.bca.org.uk - promotes cement and concrete in the UK

- www.fmb.org.uk- building industry trade association with 15,000 members
- www.epsmolders.org- dedicated to promoting and increasing the use of expanded polystyrene building and construction products
- www.decorative-concrete.net- resource center for the decorative concrete and stamped concrete industry.

Magazines and Newsletters

Several magazines and newsletters are published that provide general and specific information about the concrete construction industry, of which a few are provided below:

- The Concrete Producer. The Aberdeen Group 426 South Westgate Street, Addison, IL 60101. (800) 837-0870.
- Concrete Construction. The Aberdeen Group 426 South Westgate Street, Addison, IL 60101. (800) 837-0870.
- Concrete Homes. Publications & Communications, Inc. 505 Cypress Creek Rd., Suite B, Cedar Park, TX 78613. (512) 250-9023.
- Permanent Buildings and Foundations. Published every six weeks, PBF is a business newsmagazine for concrete residential and light commercial builders.
- Energy Design Update. Cutter Information Corp., 37 Broadway, Suite 1, Arlington, MA 02474-5552. (781) 641-5118.
- Concrete Homes. A monthly newsletter published by the Residential Department of the Portland Cement Association to communicate ideas for promoting the use of concrete in homebuilding.

Trade Organizations

The main trade organizations for the ICF construction industry include the following:

Insulating Concrete Form Association
(ICFA)
1807 Glenview Road Suite #203
Glenview, IL 60025.
Tel: (847) 657-9730
FAX: (847) 657-9728.
www.forms.org

Represents the manufacturers of ICFs and several hundred foam manufacturers, product distributors, plastics companies, concrete suppliers, contractors, and engineers. It has a wealth of information and materials for anyone interested in using or promoting ICFs.

Portland Cement Association (PCA)
5420 Old Orchard Road
Skokie, IL 60077-1083
Tel: (847) 966-6200
FAX: (847) 966-9781
www.portcement.org

Represents manufacturers of cement and cement-related products, with hundreds of other affiliates in associated businesses. It runs a large program of research on ICFs, including engineering, proper and efficient construction techniques, and advantages to the contractor and occupant. The results of this research and more are available from the association.

National Ready-Mixed Concrete Association
(NRMCA)
900 Spring Street
Silver Spring, MD 20910
Tel: (301) 587-1400
FAX: (301) 585-4219
www.nrmca.org

Represents the thousands of concrete suppliers across the country. It provides information and support to concrete providers and their customers.

Canadian Portland Cement Association
(CPCA)
60 Queen Street, Ste. 1500
Ottawa, ON K1P 5Y7, Canada
Ph: (613) 236-9471
Fax: (613) 563-4498
www.cpca.ca

Represents cement manufacturers and other concrete-related concerns in Canada. CPCA and Canadian companies pioneered much of the use of ICFs in North America. The association provides materials covering what it has learned to the general public, and provides directions to Canadian companies in the ICF and related business.

ICF System Manufacturers and Installers

Of the sites on the Internet, most of the companies that offer ICF systems have their own website homepage advertising their product. These companies, broken down into the type of ICF construction technique, include those listed Table 5-1:

PANELS	PLANKS	BLOCKS
Flat Panels ISOMAX Perma-Form Pink Form Xtra Poudrecast	Flat Planks Enermizer Lite-Form Magnum-ICF Polycrete Premere Forms Quad-Lock R-Control Referee Techsystem TF Building System Thermalite Thermalwall Building System	Flat Blocks Advantage Wallsystem Amvic Building System Blue Maxx Conform VWF Eco-Block Fold-Form Formtech GREENBLOCK Integra-Spec Strate Block
		Waffle Grid Blocks Consulwal ICE Block Polysteel REWARD Therm-O-Wall
Screen Grid Panel Luxit RASTRA ThermoFormed Block		Screen Grid Block Conform SWF Durisol Foam Wonder Wall Faswall IMF Wall Systems Insulform Insulform Wall System New Energy Wall System Perma-Form Reddi-Form Reddi-Wall Tech Block VOT Block
Post-and-Beam Panels Amhome		Post-and-Beam Blocks EnergyLock KEEVA ThermoBlock

Table 5-1. List of ICF Manufacturers [icfweb.com, 2000]

Chapter 6. Conclusions

This final chapter will include a look at ICF and wood frame owner perceptions, a summary of the key observations in this paper, and speculation regarding the future of ICF construction.

Owner Perceptions

In VanderWerf's study, owner perceptions were recorded during detailed surveys. The main topics that owners provided comments cited included comfort and related issues (81%), quietness of home (65%), energy efficiency (43%), and solidness/strength related (31%). Of the 77 respondents for ICF and wood frame homes, 99 percent of ICF and 98 percent of wood frame homes reported liking ICF homes.

The top 6 reasons that owners like ICF homes are the quietness/reduced noise, energy efficiency, comfort, even temperature, tight/no drafts, and solidness/strength of walls. The main aspect that owners disliked about ICF homes was a difficulty of hanging items on walls.

The top 6 reasons that wood frame owners cite for liking their home include the location/view, involvement in construction, layout/floor plan, comfort, new construction, and spaciousness. The main reasons for disliking frame houses included the house being too large/small, construction problems, and the layout.

Within these comparisons, note that the wood frame owners focused on items and issues that are independent of the method of construction, while the ICF owners visibly noted several aspects that exceeded performance of a wood frame house.

Key Observations

Several ICF material properties appear to objectively perform better than their wood frame counterpart. These comparisons included sound resistance, R-value, fire resistance, durability and strength of walls, energy efficiency, and owner perceptions.

Wood frame construction is less expensive than ICF construction, and barring a significant rise in the cost of wood frame construction combined with a significant drop in the cost of ICF construction, wood frame construction will continue to cost about half the cost of ICF walls. A potential ICF owner has to weigh the intangible advantages that ICF proponents advertise versus the higher capital cost of initial construction. The payback period of the initial construction cost through energy savings is nearly 15 years at the minimum, so the life cycle cost would probably not play a main economic factor toward purchasing an ICF home. The energy savings will be most apparent in a cold climate, but the savings per total heating and cooling degree-days is the same regardless of location.

Future of ICF Construction

Even though the market share of ICF construction is like "an ant colony in an elephant field", the future of ICF construction is bright, due mainly to the Partnership for Advancing Technology in Housing (PATH) program and the positive word-of-mouth advertising of ICF homeowners [PBR, May 15, 1998]. The PATH program has the potential to lead to the construction of new residential neighborhoods, in particular low-income area, exposing more contractors to ICFs. However, in order for ICFs to grow in the market, the whole chain of production and supply, marketing, education, has to be continually improved. The Evaluation Protocol for ICFs is important to establish minimum building code requirements that are universally accepted.

Some future design issues under review include the effective compressive strength of concrete and minimum reinforcing requirements. ICF walls are designed according to ACI 318, which assume the concrete strength specified; however, actual strengths of concrete walls in ICF forms actually achieve greater strengths, with values over 125% of 28 day strength due to the better than normal hydration of the concrete within the forms. The design codes are therefore conservative. Reductions in amount of concrete would reduce the price of ICF construction. Many engineers believe that the ICF wall reinforcement is over designed by ACI standards and would like to have the general standard for ICF walls reduced, which would also decrease the construction cost.

Until the ICF manufacturers and builders find a way to significantly reduce the substantial cost difference between ICF and wood frame construction, ICF proponents will struggle to obtain young, first time home buyers, which would be a significant start toward increased market share.

BIBLIOGRAPHY

American Concrete Institute. Building Code Requirements for Reinforced Concrete (ACI 318-89) and Commentary—ACI 318R-89. July 1999

American Polysteel, Inc. Polysteel Forms for Concrete User Manual. 4th Ed. Albuquerque, New Mexico. 1999.

American Polysteel, Inc. "Personal Tour of American Polysteel Plant". Gainesville, Florida. May 2000.

Amhome, Inc. Amhome, Technology's Most Energy-Efficient Home. Wesley Chapel, Florida. January 2000.

Buttle and Tuttle Ltd. Internet Web Site, www.worldclimate.com . November 2000.

ECO-Block, Inc., ECO-Block Installation Manual and Brochure. 2000.

ECO-Block, Inc. Internet Web Site, www.eco-block.com. November 2000.

ICFWeb.com. The On-line Community for the Insulating Concrete Form Industry, www.icfweb.com. November 2000.

Keeva International, Inc. Keeva ICF Roof & Floor, Post and Beam Wall Systems. Chandler, Arizona. 1997.

K-X Faswall Inc. General Application and Technical Information. Windsor, South Carolina. 2000.

National Evaluation Service, Inc. Evaluation Protocol for Insulating Concrete Form Technology (First Public Review Draft). October 24, 2000.

National Association of Home Builders (NAHB) Research Center, Inc. Building Better Homes at Lower Costs, The Industry Implementation Plan for the Residential National Construction Goals. January 13, 1998.

National Association of Home Builders (NAHB) Research Center, Inc. Prescriptive Methods For Insulating Concrete Forms in Residential Construction. May 1998.

National Association of Home Builders (NAHB) Research Center, Inc. Insulating Concrete Forms for Residential Construction-Demonstration Homes. Upper Marlboro, Maryland. July 1997.

National Association of Home Builders (NAHB) Research Center, Inc. Concrete Homes Versus Wood Frame Homes-Installed Cost, Acoustic, and Thermal Performance. Upper Marlboro, Maryland. December 1998.

National Evaluation Service, Inc. Internet Web Site, www.nateval.org. November 2000.

Partnership for Advancing Technology in Housing (PATH). Internet Web Site, www.pathnet.org. November 2000.

Portland Cement Association. Internet Web Site, www.concretenetwork.com. November 2000.

Permanent Buildings and Foundations (PBR). Building Codes; How They Are Developed and Why. Permanent Buildings and Foundations (February 15, 1997): 30.

Permanent Buildings and Foundations (PBR). What It Takes To Get ICF Building Code Approval. Permanent Buildings and Foundations (January 1, 1998): 24.

Permanent Buildings and Foundations (PBR). Getting Ready for the Shift. Permanent Buildings and Foundations (May 15, 1998): 22-23.

Permanent Buildings and Foundations (PBR). Concrete Walls Protect Best Against Wind-Blown Debris. Permanent Buildings and Foundations (October 1, 1998): 5.

R.O. Camp. "Personal Tour of Gainesville Technology Center under Construction". Gainesville, Florida. June 2000.

VanderWerf, Pieter A. Energy Comparisons of Concrete Homes Versus Wood Frame Homes. Portland Cement Association RP 119. 1998.

VanderWerf, Pieter A., et al. Insulating Concrete Forms for Residential Design and Construction. 1st ed. New York. McGraw-Hill, 1997.

APPENDIX: PowerPoint Presentation

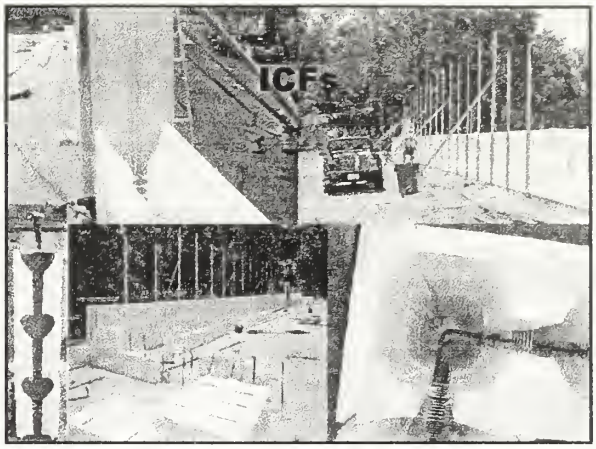
The following PowerPoint presentation was presented by Dan C. Lewis in partial fulfillment of the degree of Master of Engineering to graduate committee faculty members Dr. Charles Glagola, Dr. Zohar Herbsman, and Dr. Ralph Ellis at 12:00 p.m., November 28, 2000 at University of Florida, Weil Hall, Room 245.

Use of Insulating Concrete Forms in Residential Housing

Dan C. Lewis

28 Nov 2000

A REPORT PRESENTED TO THE GRADUATE COMMITTEE OF THE DEPARTMENT OF CIVIL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING



Topics Presented

- Current Status of ICFs
  - Government Programs
  - Building Codes
  - Barriers

Topics Presented

- Types of ICFs
  - Forms & Shapes
  - Manufacturing Process
  - Plastic Foams
  - Design Basis

Topics Presented

- Comparisons between ICF vs. Wood
  - 3 Main Studies
  - Construction Costs
  - Fire Resistance
  - Acoustical Properties
  - Durability & Strength of Walls

Topics Presented

- Energy Comparisons
  - Thermal Mass
  - Consistency of Insulation
  - Air Infiltration
  - R-Values
  - Sources of Energy Loss
  - Climate/Location Effects on Costs
  - Payback—Life Cycle Costs

Topics Presented

- Sources
- Conclusions
  - Owners Observations
  - Would I buy an ICF home?
  - Future of ICF construction

Current Status of ICFs

- Partnership for Advancing Technology in Housing (PATH)
  - Established 1998
  - Government/Private venture to explore new technologies for Housing
  - ICF one of many technologies
    - Foundations
    - Exterior Walls

Current Status of ICFs

- National Construction Goals (1994)
  - 50% Greater Durability/Flexibility
  - 50% Reduction in Delivery Time
  - 50% Reduction in Energy/O&M Costs
  - 30% Increase in Occupant Comfort
  - 50% Fewer Facility Related Injuries
  - 50% Less Waste & Pollution
  - 50% Reduction in Construction Injuries

Current Status of ICFs

- Main Strategies to Meet Goals
  - Establish Information Infrastructure
  - Methods for Assessing Durability
  - Improve Efficiency of Production Process
  - Improve New Product Approval Processes
  - Endorse Commercialization of Innovation
  - Expand Markets

Current Status of ICFs

- Evaluation Protocol for ICFs
  - Standardization for Building Code Acceptance
  - Currently under Public Review
  - Goals:
    - Uniformity in Data Acquisition & Analysis
    - Uniform Comparison of ICF Technologies
    - More Timely Technology Evaluation & Deployment

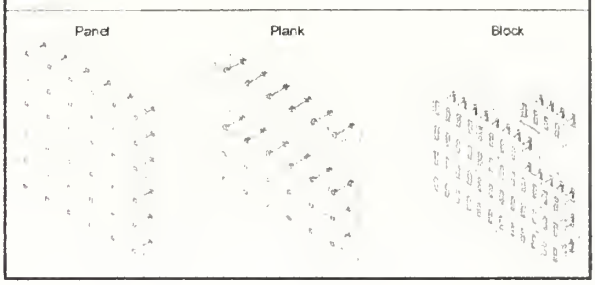
Current Status of ICFs

- Evaluation Protocol for ICFs
  - Structural Properties
  - Fire Properties
  - Thermal Resistance Properties
  - Termite Protection
  - Dampproofing & Waterproofing
  - Independent Laboratory
  - Construction Documentation
  - Inspections
  - Durability

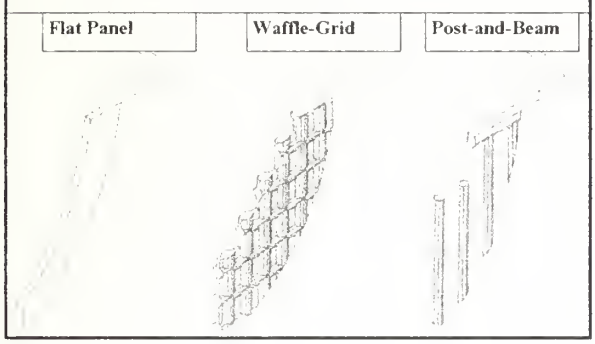
Current Status of ICFs

- Barriers to Advancement of ICF Technology
  - Fragmented Industry Structure
  - Exposure to Liability
  - Cyclical Nature of Construction
  - Lack of Access to Information
  - Need for Education & Training
  - Building Code & Product Approval Systems
  - Limited Funding for Nonproprietary Research
  - Market Resistance

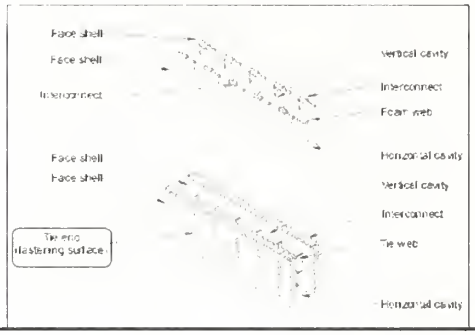
Types of ICFs—Forms



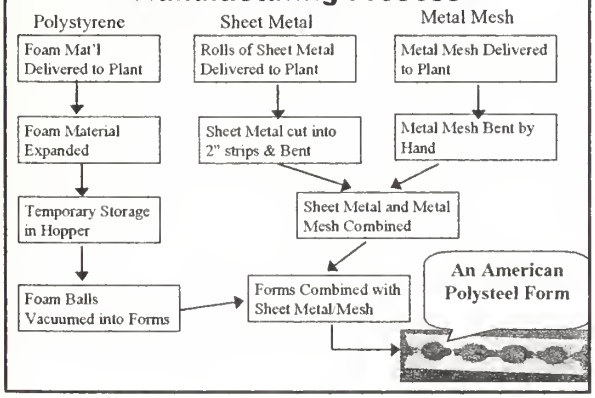
Types of ICFs—Shapes

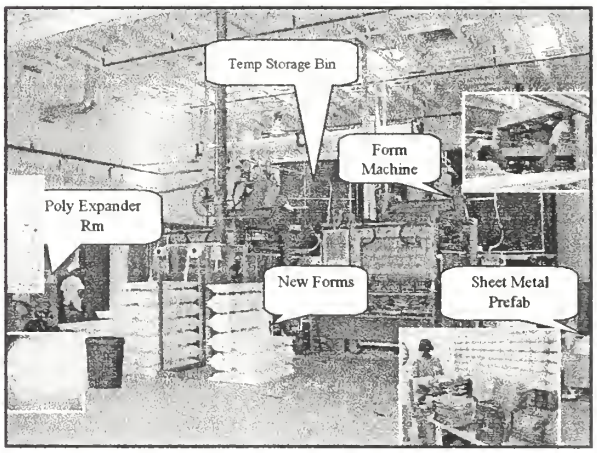


Types of ICFs—Parts

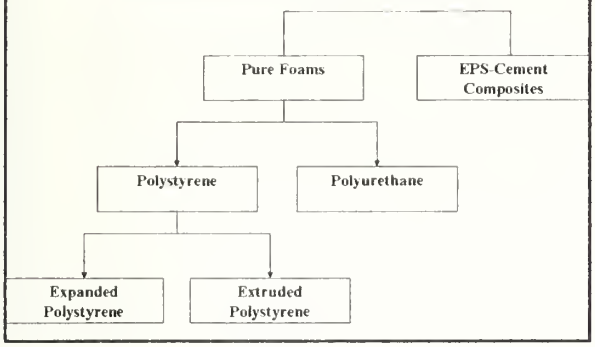


Manufacturing Process





Types of ICFs—Foams



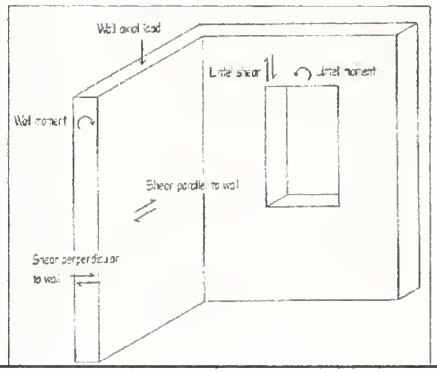
Types of ICFs—Foams

- Differences between Foams
  - Most Dense: Composite
  - Best R-Value: Polyurethane
  - Compressive/Flexural Strength: Composite
  - Water Vapor Permeance: Polyurethane
  - Water Absorption: XPS
  - Flame Spread: XPS
  - Smoke Developed: EPS
  - Most Expensive: Polyurethane ($0.70/bd ft)
  - Least Expensive: EPS ($0.17/bd ft)

Structural Design

- ACI 318 Governs Design
  - Flat Walls—Chapter 14
  - Grid/Waffle Walls—Chapter 14, 22
  - Post and Beam Walls—Chapter 10

Types of ICFs—Forces Analyzed



Typical Design Loads

- Wind Load—25 psf
- Roof Live Load—20 psf
- Roof Dead Load—20 psf
- Floor Live Load—40 psf
- Floor Dead Load—10 psf

Comparisons

- VanderWerf Study
  - 29 Pairs of Homes (10 Regions)
  - Normalized
    - 2100 SF
    - 2 Stories & Basement Foundation
    - 3 Occupants
    - 69°-74°F in Winter-Summer
    - Heating/Cooling Equip. Efficient (100%/285%)

Comparisons

- NAHB Research Center (2 Studies)
  - Maryland (2 ICF, 1 Wood)
  - Virginia, Iowa, Texas

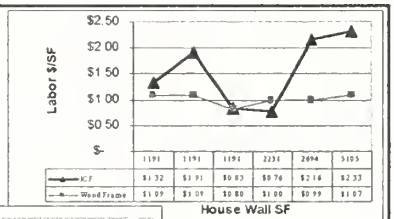
Constructability

- ICF Requires Better Planning
- Contractors More Familiar with Wood
- Account for Thicker Walls
- Building Code Permits
  - Reinforcing Requirements
  - Termite Protection
  - Moisture Control
  - Seismic & Wind Resistance

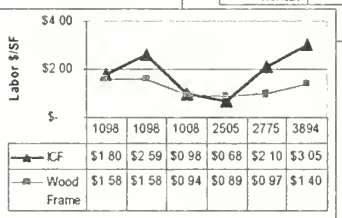
Construction Cost

- Reviewed Labor, Material, Total Costs
- Cost Comparisons
  - $$$/Wall SF
  - $$$/Floor SF

Labor Cost



	1191	1191	1191	2231	2694	5105
ICF	$1.32	$1.91	$0.83	$0.76	$2.16	$2.33
Wood Frame	$1.09	$1.09	$0.80	$1.00	$0.99	$1.07

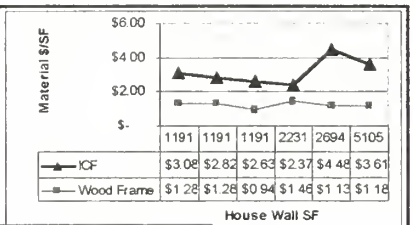


	1098	1098	1008	2505	2775	3894
ICF	$1.80	$2.59	$0.98	$0.68	$2.10	$3.05
Wood Frame	$1.58	$1.58	$0.94	$0.89	$0.97	$1.40

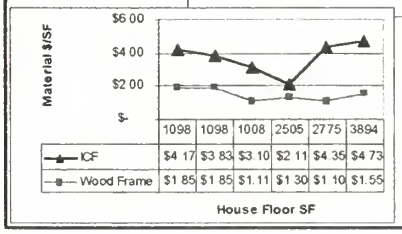
Avg: $1.86 vs. $1.23

ICF 52% More Expensive

Material Cost



	1191	1191	1191	2231	2694	5105
ICF	$3.08	$2.82	$2.63	$2.37	$4.48	$3.61
Wood Frame	$1.28	$1.28	$0.94	$1.46	$1.13	$1.18



	1098	1098	1008	2505	2775	3894
ICF	$4.17	$3.83	$3.10	$2.11	$4.35	$4.73
Wood Frame	$1.85	$1.85	$1.11	$1.30	$1.10	$1.55

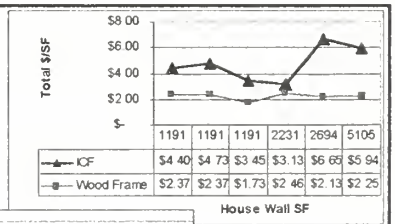
Avg: $3.71 vs $1.46

ICF 167% More Expensive

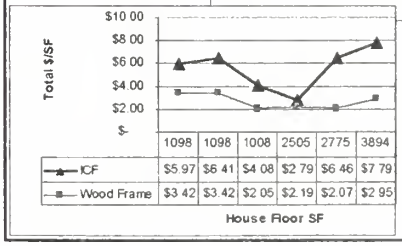
ICF: 67% of Total

Wood: 54% of Total

Total Cost



	1191	1191	1191	2231	2694	5105
ICF	$4.40	$4.73	$3.45	$3.13	$6.65	$5.94
Wood Frame	$2.37	$2.37	$1.73	$2.46	$2.13	$2.25



	1098	1098	1008	2505	2775	3894
ICF	$5.97	$6.41	$4.08	$2.79	$6.46	$7.79
Wood Frame	$3.42	$3.42	$2.05	$2.19	$2.07	$2.95

Avg: $5.57 vs $2.69

ICF 107% More Expensive

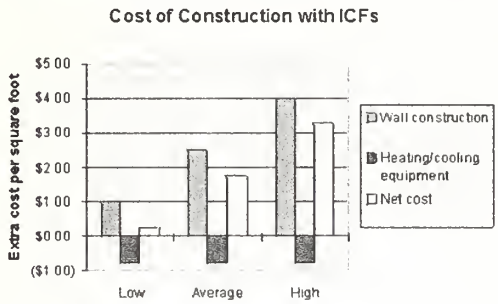
Construction Cost

- Conclusions
  - Wood Frame Prices More Stable
  - ICF 2X More Expensive on Average
  - Cost/SF Generally Increases with House Size

Construction Time

- Foundations: ICF Faster than CMU
- Walls: Wood Erected Faster
- Overall: Times Comparable

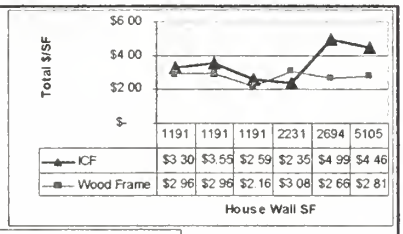
Construction Cost Offsets



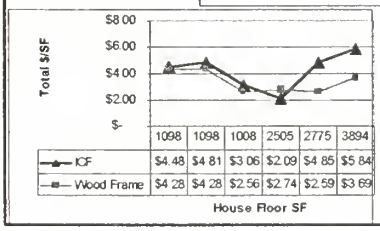
What If???

- ICF Costs of Construction Decreased by 25%
- Wood Frame Costs Increased by 25%

What If?



	1191	1191	1191	2231	2694	5105
ICF	$3 30	$3.55	$2 59	$2 35	$4 99	$4 46
Wood Frame	$2 96	$2 96	$2.16	$3 08	$2 66	$2 81



	1098	1098	1008	2505	2775	3894
ICF	$4.48	$4 81	$3 06	$2.09	$4 85	$5 84
Wood Frame	$4 28	$4 28	$2.56	$2.74	$2.59	$3 69

Avg: $4.18 vs $3.36 ICF 25% More Expensive

Overall, ICF price would be 0.8% greater than Wood price

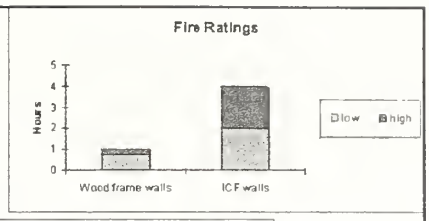
Likelihood?

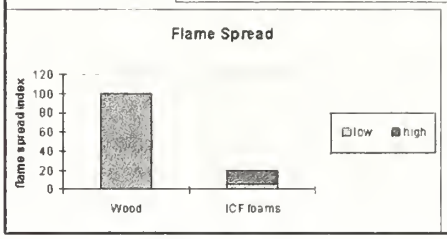
- ICF Components
  - Labor—Not Likely
  - Materials
    - Concrete—Not Likely
    - ICF Blocks—POSSIBLE
  - Total—Not Likely to Come down 25%
- Wood Frame
  - Labor—Not Likely
  - Materials—Wood Prices Not likely to Double

Fire Resistance

- Possible Fire Scenarios
  - Walls Fail Structurally
  - Walls Allow Fire to Pass Through
  - Materials in Wall Add Fuel to Fire
  - Materials Emit Fumes that Asphyxiate

Fire Ratings

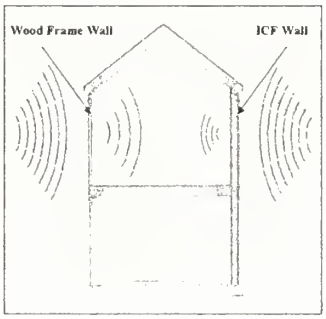




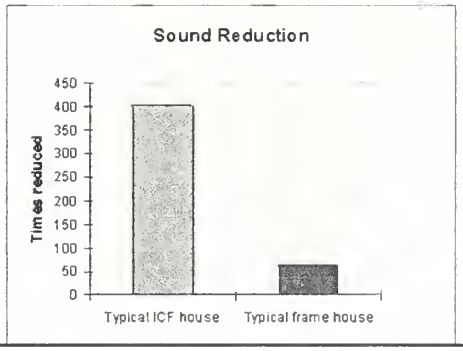
Flame Spread

Sound Resistance

- ICFs have higher STC ratings
- Wood (STC 36)
- ICF (STC 44-58)



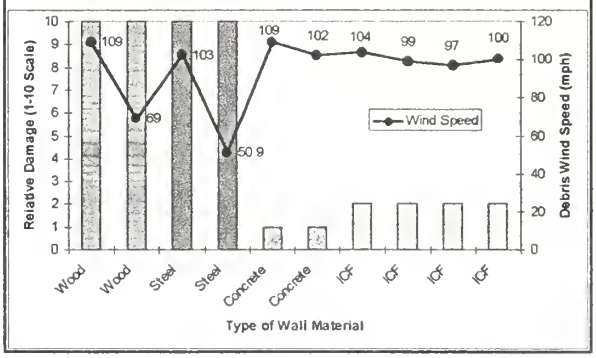
Sound Reduction



Durability & Strength

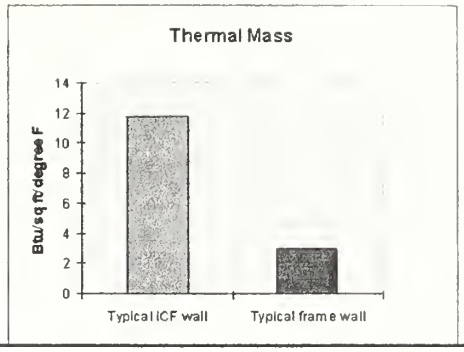
- ICF (Concrete Walls) Much Stronger
- Missile/Debris Tests Performed
- 2x4 Stud Missiles Projected at Varying Speeds

Missile/Debris Tests

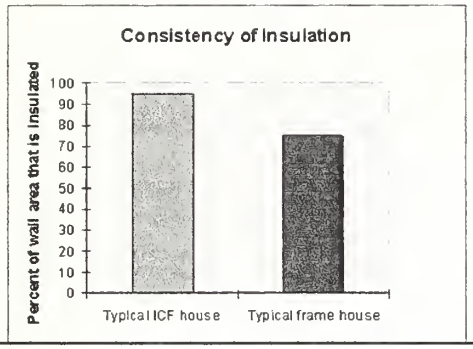


Energy Comparisons

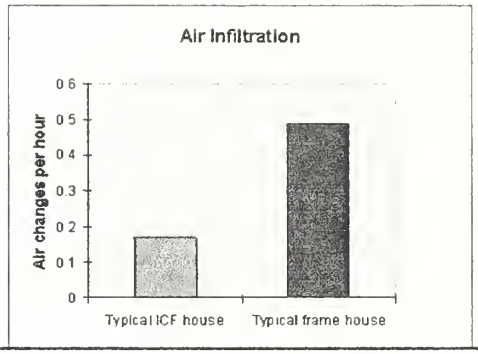
Thermal Mass



Consistency of Insulation



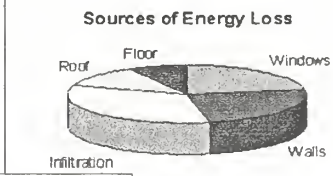
Air Infiltration

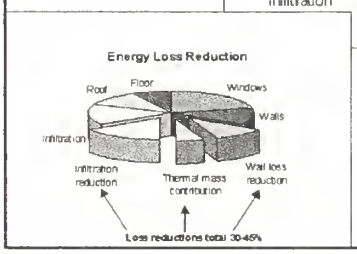


R-Values

- ICF Ranges average 23-35
- Wood Frame average 15-19

Energy Loss

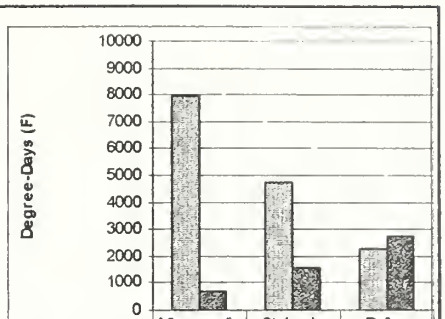




Climate Impact on Energy Costs

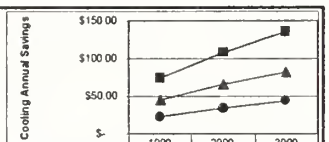
- Relationship between Climate and Energy Savings is Important
- Climate is broken into Heating and Cooling Degree Days
- Looked at 3 Cities in Cold, Moderate, Warm Climates

Degree-Days



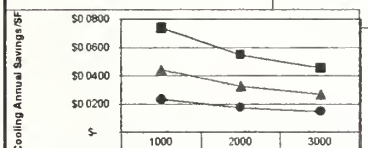
	Minneapolis	St. Louis	Dallas
Heating	7949	4757	2259
Cooling	680	1534	2763
Total	8629	6291	5022

Cooling Savings



	1000	2000	3000
Minneapolis	$23.35	$34.20	$42.98
St Louis	$44.32	$64.90	$81.57
Dallas	$73.98	$108.30	$136.12

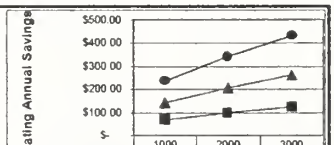
Square Feet



	1000	2000	3000
Minneapolis	$0.0234	$0.0171	$0.0143
St Louis	$0.0443	$0.0325	$0.0272
Dallas	$0.0740	$0.0542	$0.0454

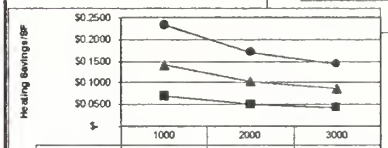
Square Feet

Heating Savings



	1000	2000	3000
Minneapolis	$233.67	$342.17	$430.08
St Louis	$141.07	$206.58	$259.65
Dallas	$68.63	$100.06	$125.78

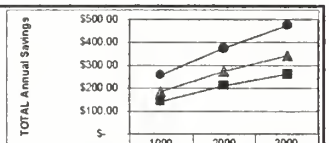
Square Feet



	1000	2000	3000
Minneapolis	$0.2337	$0.1711	$0.1434
St Louis	$0.1411	$0.1033	$0.0868
Dallas	$0.0686	$0.0500	$0.0419

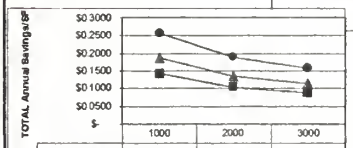
Square Feet

Total Savings



	1000	2000	3000
Minneapolis	$257.03	$376.37	$473.06
St Louis	$185.39	$271.48	$341.22
Dallas	$142.29	$208.36	$261.89

Square Feet

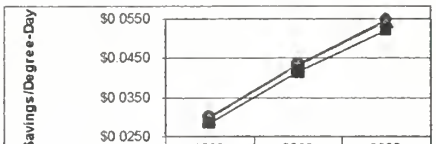


	1000	2000	3000
Minneapolis	$0.2570	$0.1882	$0.1577
St Louis	$0.1854	$0.1357	$0.1137
Dallas	$0.1423	$0.1042	$0.0873

Square Feet

Location Bottom Line

- Savings are Directly Related to Number of Heating and Cooling Degree Days



	1000	2000	3000
Minneapolis	$0.0298	$0.0436	$0.0548
St Louis	$0.0295	$0.0432	$0.0542
Dallas	$0.0283	$0.0415	$0.0521

Square Feet

Economic Payback

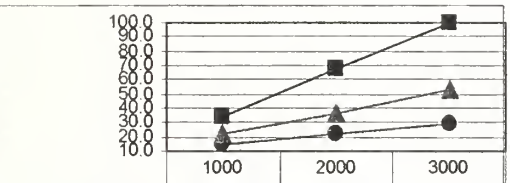
- Capital Costs vs. Energy Savings
  - What is Time of Payback
- Up to 44% Savings on Heating
- Up to 32% Savings on Cooling
- Average ICF Capital Cost (+3%)
- Rate of Return (Conservative 3%)
- Present Worth Analysis

Economic Payback

Wood Price = ICF Price – Savings (P/A, 3%, N Yrs)

Where:
Wood Price = The new price of wood framed house at $100/SF
ICF Price = The new price of ICF House (Wood Price * 103%)
Savings = Annual Savings (From Figure 4-11)
(P/A, 3%, N) = Present Worth Given Annual Savings, 3% Rate of Return
N = The number of years where the extra cost of ICF home is amortized.

Payback Times



	1000	2000	3000
Minneapolis	14.6	22.0	28.6
St Louis	22.5	36.8	53.0
Dallas	33.9	67.5	100.0

Square Feet

ICF Sources

- Internet
- Magazines/Newsletters
- Books
- Trade Organizations
- ICF Companies

Conclusions

- ICF Owner Perceptions (99% Like)
  - Comfort
  - Quietness
  - Energy Efficiency
  - Solidness/Strength
  - Problem: Hanging Items on Walls

Conclusions

- Wood Owner Perceptions
  - Location/View
  - Involvement in Construction
  - Layout/Floor Plan
  - Comfort
  - New Construction
  - Spaciousness
  - Problems: Too Large/Small, Construction Problems, Layout

Conclusions

- Wood Owners Focused on Items Independent of Method
- ICF Owners Focused on Aspects Noticeably Better than Wood Homes

Key Observations

- ICFs Perform Better
  - Sound Resistance
  - Fire Resistance
  - Strength & Durability
  - Energy Efficiency
  - Owner Perceptions
- Economic Considerations
  - Payback Not Justified for Average Owner
  - Buy ICF for NON-Economic Considerations

Future of ICFs

- PATH Program
- National Construction Goals
- Word-of-Mouth from ICF Owners
- Evaluation Protocol for ICFs
- Design Considerations
  - Concrete & Reinforcement
- Future Directly Depends on Ability to Reduce Costs to Better Compete with Wood Frame

The End

Thank you for your time

72 290NPG TH 3147
6/02 22527-200 NLB

DUDLEY KNOX LIBRARY
3 2768 00403925 5